RCOP

Research Center for Optical Physics
FINAL REPORT 1992 - 1996

HAMPTON UNIVERSITY
DEPARTMENT OF PHYSICS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NAGW-2929

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1. EXECUTIVE SUMMARY

During the five years since its inception, RCOP has excelled in the goals stated in the original proposal: 1) training of the scientists and engineers needed for the twenty-first century with special emphasis on underrepresented citizens and 2) research and technological development in areas of relevance to NASA.

In the category of research training, there have been 16 Bachelors degrees and 9 Masters degrees awarded to African American students working in RCOP during the last five years. RCOP has also provided research experience to undergraduate and high school students through a number of outreach programs held during the summer and the academic year. RCOP has also been instrumental in the development of the Ph.D. program in physics which is in its fourth year at Hampton. There are currently over 40 graduate students in the program and 9 African American graduate students, working in RCOP, that have satisfied all of the requirements for Ph.D. candidacy and are working on their dissertation research. At least three of these students will be awarded their doctoral degrees during 1997.

RCOP has also excelled in research and technological development. During the first five years of existence, RCOP researchers have generated well over $3 M in research funding that directly supports the Center. Close ties with NASA Langley and NASA Lewis have been established, and collaborations with NASA scientists, URC's and other universities as well as with industry have been developed. This success is evidenced by the rate of publishing research results in refereed journals, which now exceeds that of the goals in the original proposal (~2 publications per faculty per year). Also, two patents have been awarded to RCOP scientists.

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2. MISSION AND VISION

The mission of the Research Center for Optical Physics is to: 1) promote world–class leadership in selected areas of optical sciences and technologies and 2) develop under-utilized human resources to meet the nation's science and engineering manpower needs in the twenty-first century.

The vision of RCOP is to establish Hampton University as a premier institution for optical scientific advancement and education in the mid-Atlantic United States.

There are three areas of research that form the goals of the Center's strategic focus:

- Atmospheric Sciences and Optical Remote Sensing Technology
- Optical Materials (including laser, nonlinear optical and smart materials development)
- Non-Intrusive Diagnostics

RCOP has developed significant capabilities in these areas and will continue to be integrated intimately into NASA Langley's aerospace and atmospheric science research priorities. Our specific goals are to: (1) develop an observatory based LIDAR remote sensing facility on Hampton University's campus for use by NASA and RCOP personnel, (2) develop optical remote sensing techniques of crucial value to NASA Langley's Atmospheric Science objectives, (3) transfer RCOP developed spectroscopic flow analysis technique to NASA Langley's wind tunnel operations, (4) conduct spectroscopic analyses on optical materials developed at Langley and other university and industrial institutions and (5) demonstrate fiber optic sensor integration into NASA relevant structures.

RCOP Students

All of the students in the Department of Physics, as well as students from other departments, participate in research through interaction with physics faculty as mentors. In particular, the research activities in RCOP have provided Hampton University students with a wealth of opportunities for participation in frontline research using state-of-the-art technology. In the five years since the inception of RCOP, 16 students have received bachelors degrees and 14 have received masters degrees while working for RCOP faculty. Currently, there are eleven graduate students in optics that have passed the Ph.D. qualifying examination and are working on their dissertation research and ten graduate students working on Masters projects. The ethnic distribution of these students is shown in Figures 1 and 2.

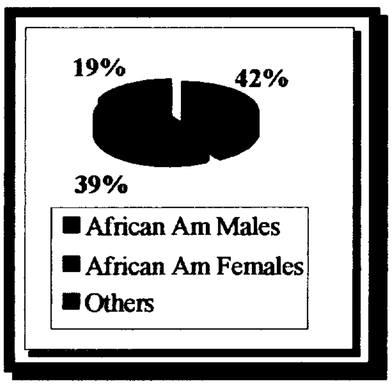


Figure 1. Ethnic distribution of the thirty RCOP students that graduated with a Bachelors or Masters degree during 1992 - 1996.

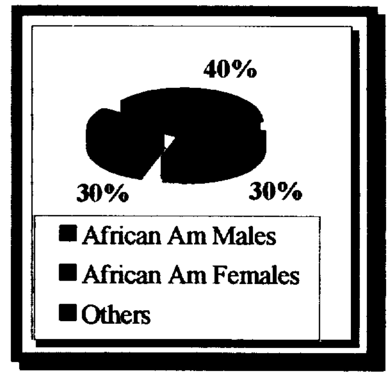


Figure 2. Ethnic distribution of the ten RCOP Ph.D. candidates.

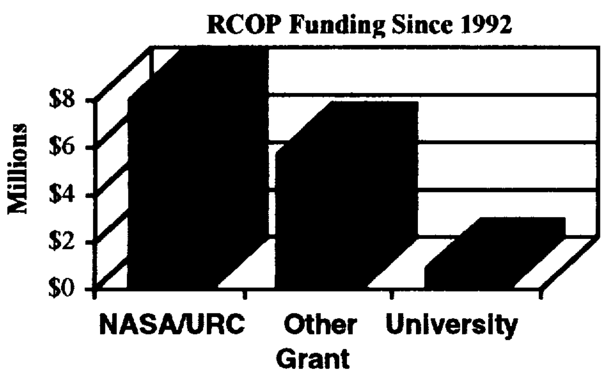


Figure 3. Distribution of funding, in millions of dollars, generated for RCOP related activities from 1992-1996.

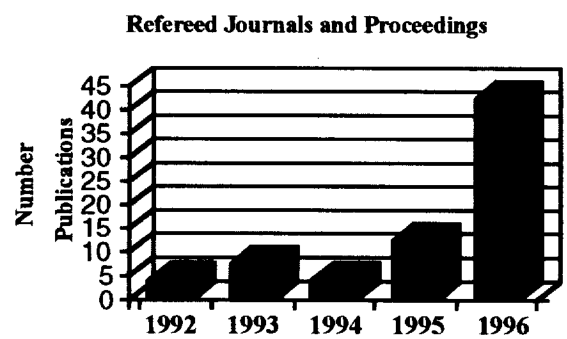


Figure 4. Number of refereed journals and proceedings from 1992 - 1996. The 1996 number includes submitted work.

Research Funding and Publications

During the period covering 1992 - 1996, the Department of Physics generated approximately $17 million in external funding. Also during that period, RCOP faculty and students received grants, scholarships, fellowships and equipment donations totaling over $5.7 million. After this five year startup period, generation of refereed publications by RCOP faculty has reached the level expected for a world-class research center of this size.

3. RESEARACH SUMMARY

3.1 Non-Intrusive Optical Diagnostics

Investigator: Dr. Bagher M. Tabibi

Adjunct Professor
Dr. Ja Lee
Postdoctoral Fellow
Dr. Yoon Choi
Ph.D. Candidates
Mr. Charles Terrell
Mr. Dung Nguyen
Ms. Cecily Smith

M.S. Candidates
Myo Thaik

Undergraduate Students
Tyhesha Goss
Tosha Hudson

Projects: Electron-Beam Fluorescence (EBF), Laser-Induced Fluorescence (LIF), and Focusing Schlieren Techniques for Fast Flowfield Characterization.

Partners: Measurement Science and Technology Branch, NASA LaRC and Air Force Office of Scientific Research (AFOSR)

Research Goals: The research goals of the non-intrusive optical diagnostics were:

To detail the flow analysis of the High-speed Flow Generator (HFG) atNASA, LaRC; to visualize the low-density supersonic/hypersonic flows;to measure the flow velocity at the nozzle exit of the Solar Thermal-ElectricPropulsion (STEP) system at Hampton University.

Accomplishments: Developed, installed, and applied of the EBF technique to the fast flowfield; built and employed of a very high sensitivity focusing schlieren device; set up of an excimer pumped tunable dye laser for the LIF technique in STEP system.

Indeed we aimed to significantly contribute toward the NASA-Langley's related research projects, which include Advanced Subsonic Technology, High Speed Research, and Hypersonic Propulsion.

Program Management: Dr. Bagher Tabibi has managed the research program. Three Graduate Research Assistants (two Ph.D. level and one M.S. level) and one undergraduate student have been working in this program. To enhance the productivity of this program, Dr. Ja H. Lee, retired Senior Research Scientist of NASA-LaRC, jointed as Adjunct Professor and has devoted 20% of his time to advise the graduate students on their research activities.

A table-top wind tunnel experiment in the Graduate Physics Research Center (GPRC), the Solar Thermal-Electric Propulsion (STEP) System of Advanced Propulsion Laboratory (supported by the AFOSR grant) at Hampton campus, and the HFG Facility at the Measurement Science and Technology Branch of NASA-LaRC were maintained for these research program.

3.1.1 Technical Accomplishments

Electron-Beam Fluorescence

The EBF technique has been used extensively to the low-densities ($< 10^{16}$ cm^{-3}) supersonic wind tunnels to measure the local densities, temperatures and velocities of the molecular species[1-3] The principles of this technique are:

Neutral gas molecules, in state E_0, are excited to state E_1 by the inelastic collision with electrons in the beam according to the following

$e^- + A(E_0) \Rightarrow A^*(E_1) + e^-$.

The excited gas molecules decay to a lower state (E_2) emitting photons (fluorescence) in the process

$A^*(E_1) \Rightarrow A(E_2) + h\nu$.

Spectral analysis of the characteristic fluorescence can determine local and global properties of the neutral gas in the flow.

Density Measurement. The number density can be measured from the intensity of the vibrational or rotational spectral lines according to[1]

$$I = \frac{nC_o}{1 + Q_{nm}}$$

where $Q_{nm} = 2n\sigma^2 \frac{(4\pi kT)^{1/2}}{A_{nm}}$

is a quenching or collision rate term, with

n = number density of the gas,

σ^2 = quenching collision cross section.

m = mass of a molecule,

k = Boltzmann's constant,

T = gas temperature,

A_{nm} = Einstein's spontaneous transition probability,

C_0 = is a constant.

Velocity Measurement. The flow velocity, *u*, may be determined by a measurement of the Doppler effect. The velocity can be derived from the change in wavelength by equation

$$\frac{u}{c} = -\frac{\lambda - \lambda_o}{\lambda_o}$$

where c is the speed of light and λ-λ_o is the Doppler shift of a fluorescence line at λ_0. Since the shift is very small, a ultra-high resolution spectrometry which utilizes interferometric optics is necessary.

Temperature measurement. Usually three mode temperatures, translational, vibrational, and rotational, can be defined and are very helpful to understand the physical behavior of the molecular flowfield. A spectroscopic analysis of the fluorescence of gas flow provides these information. Translational temperature can be obtained from the velocity distribution measurement. In thermal equilibrium for the translational mode this function is given by the Maxwellian distribution:

$$f(u) = n(\frac{m}{2\pi kT})^{3/2} \exp\left\{-\frac{m(u-u_o)^2}{2kT}\right\}$$

where u = velocity of the particles. u_o = bulk velocity, T = gas temperature, and n, m, and k are defined above. The distribution function can be derived from the measured spectral profile of a single optical line of wavelength λ_o , emitted from the particle excited by an electron beam.

The vibrational and rotational temperatures can be obtained from the intensity measurements of the spectral lines in the vibrational and rotational bands of the molecules, respectively.

3.1.2 Experimental Results

A schematic of the EBF system is shown in Figure 5. The system mainly consists of a commercially available electron gun, a stainless steel vacuum chamber, vacuum pumping system, spectroscopic system, gas supply, and focusing optics. One or two gases can be mixed and flowed into the continuously-pumped vacuum chamber until a static pressure is reached. The electron gun, maintained at a pressure of less than 10^{-4} Torr, can then be energized between 100 eV and 10 keV. The beam of electrons (between 1 and 2 mm diameter) traverses the chamber, passes through the gas at the center of the chamber, and is collected by a faraday cup, which collects the beam current. The fluorescence emission produced is then observed through an 80 mm diameter quartz window and focused, with a 150 mm quartz lens, into the entrance slit of a 0.22 m double spectrometer. The 0.22-m double spectrometer provides dispersion (with two 1200 gr/mm holographic gratings) at the exit slit where a photomultiplier tube is mounted to amplify the signal. The spectral information can then be sent to a computer where it was displayed and analyzed.

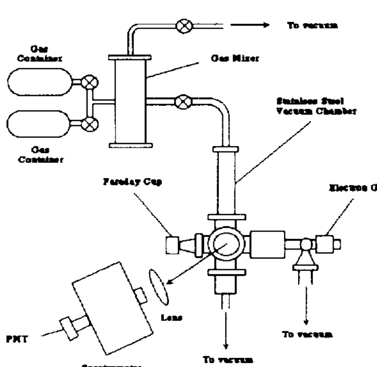


Figure 5. Diagram of the Electron Beam Fluorescence system.

The EBF system was calibrated with N_2 gas to evaluate its sensitivity and reliability for application to high-speed aerodynamic flowfields. Among many channels of electron-N_2 collisional kinetics, excited molecular nitrogen ions, N_2^{+*}, are mainly produced in the reaction

$$e^- + N_2 \dashrightarrow N_2^{+*}(B^2\Sigma_u^+) + 2e^-.$$

This is followed by the emission of fluorescence in the First Negative band,

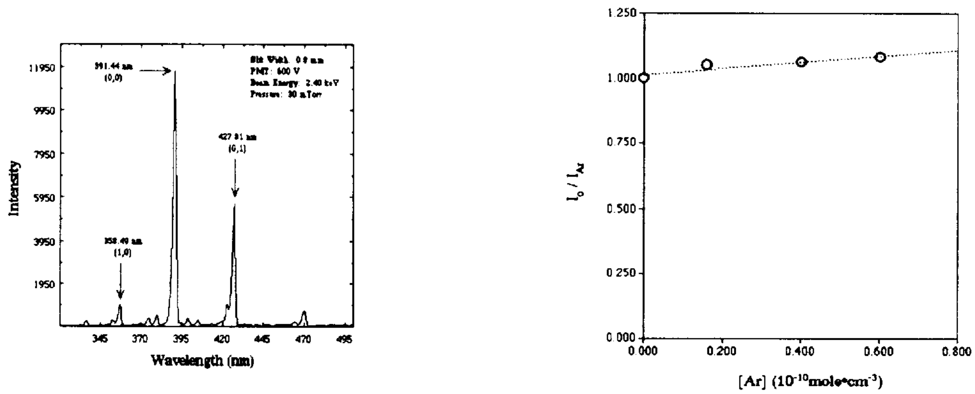
$$N_2^{+*} \dashrightarrow N_2^+(X^2\Sigma_g^+) + h\nu$$

with the (0,0) vibrational transition (at λ = 391.44 nm) being the most intense feature and considered to be a sensitive probe for N_2 concentration.

Figure 6 shows some of our preliminary experimental results. Figure 6a is a typical emission spectrum of N_2^+ emission in the First Negative band between 320 and 500 nm. We were also able to determine the quenching rate of N_2^+ emission (at λ = 391.44 nm) by argon in order to shed some light on the radiative properties of hypersonic aerospace vehicle bow-shock layers[4-5]. We calculated a quenching rate, k_q, in the order of 10^{16} $cm^3 mol^{-1} s^{-1}$from the result shown in Figure 6b. This is two orders of magnitude higher than we anticipated (k_q is typically less than 4.5 x 10^{14} cm^3 mol^{-1} s^{-1} for N_2^+ + Ar)[6]. The source of errors have been investigated but could not account this excessive rate.

We concluded that some other reaction pathways, such as charge exchange between N_2^+ and Ar
and the removal of the electron flux by collisions with Ar, should be evaluated in future.

Figure 7 shows the layout of the HFG facility in Room 123, MSTB, NASA LaRC. An 80 m^3 tank is maintained under vacuum by two high capacity (30,000 cfm) mechanical pumps. N_2 gas is entered into the test chamber through a nozzle (1.0, 3.0, or 5.0 mm in diameter). Our electron gun is connected to the test chamber for injecting the e-beam into the flow. The beam of electrons traverses the chamber and strikes the flowing gas causing it to fluoresce. The fluorescence signal is collected at 90° to the e-beam by a lens, and directed to the intensified CCD camera for flow visualization or double-grating spectrometer for spectral analysis.



(a) (b)

Figure 6. (a) Typical fluorescence emission spectrum of N_2^+ First Negative Band. (b) N_2^+ emission (at λ = 391.44 nm) quenching as a function of argon concentration. Note I_0 is the intensity for pure N_2.

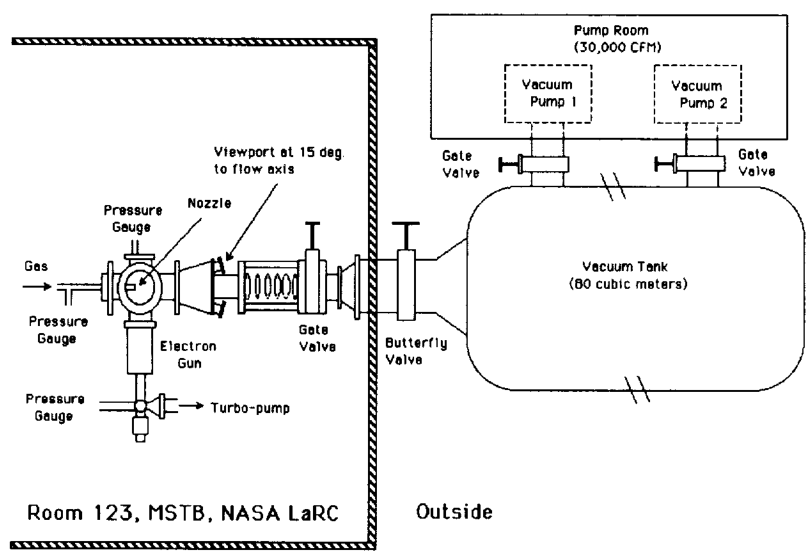


Figure 7. Layout of the High-Speed Flow Generator

Preliminary Results:
Figure 8 shows the free-jet expansion through a 5.0 mm nozzle (top three pictures) and when a 12.0 mm diameter spherical barrier is placed in front of the nozzle(bottom three pictures). The free-jets were produced by expansion of N_2 at stagnation pressure of 200 psig. The static pressure in the chamber was approximately 1 Torr.

Figure 8. Visualized flowfield of N_2 in the HFG system using EBF

The flow visualizations by the EBF technique is under evaluation by comparing with the images of focusing schlieren technique. Since these images are in digital format, the image enhancement software could be used for quantitative analysis. The results of this research will be reported soon.

Focusing Schlieren Technique

The Focusing Schlieren technique has several advantages for flow visualization because it produces a natural, easily-interpretable image of refractive-index-gradient fields. This low-cost technique also can be made for a very large field of view, high focusing capability, or high sensitivity. Figure 9 shows the layout of the optical components of a Focusing Schlieren system designed for a very high-sensitivity in order to visualize the low-density hypersonic flow of NASA's HFG. The field of view of this system is approximately 0.15 m in diameter. This system consists of a source grid and a cut-off grid (located on opposite sides of the flowfield and function as an array of knife edges), a light source, a Fresnel lens, an image lens, and an intensified CCD camera. Refraction of the collimated light beam through the flow region moves the image of the source relative to the knife edge, which results in a change in the brightness at the image plane of the CCD camera which is placed behind the cut-off grid.

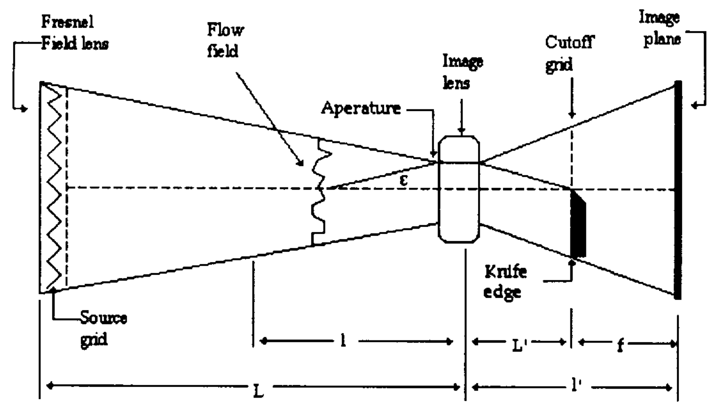


Figure 9. Layout of optical components of a small-field, high-sensitivity Focusing Schlieren system.

A Focusing Schlieren system is characterized by its sensitivity, resolution, and depth of focus[5]. The sensitivity of the system is defined by the angle of deflection normal to the knife edge. If this angle is shown by ε', the image of the source shifts by $\Delta a = \varepsilon' L'$, where a is the light source image height above the cut-off grid, and L' is the distance from the lens to the cut-off grid. This results in a change in intensity

$$\frac{\Delta I}{I} = \frac{\Delta a}{a} = \varepsilon'\left(\frac{L'}{a}\right)$$

If we use the criterion that the smallest change in brightness that can be detected is 10%, the sensitivity of the system becomes $\varepsilon' = 0.1(a/L')$, and this quantity is defined as

$$\varepsilon'_{min} = 20626\left(\frac{a}{L}\right) \text{ arcsec}$$

Due to the non-parallel nature of the light, the sensitivity of the Focusing Schlieren is:

$$\varepsilon'_{min} = \frac{20626aL}{L'(L-l)} \text{ arcsec}$$

where, L is the distance from the source grid to the lens and l is the distance from the flowfield object to the lens.

Figure 10 shows a diagram of the small-field, high brightness, and highly-sensitive Focusing Schlieren system incorporated into the High-Speed Flow Generator (HFG) at NASA LaRC. The parameters chosen for this system are: $L = 7.6$ m, $L' = 1.17$ m, $l = 4.6$ m, and $a = 0.038$ mm. The resulting sensitivity $\varepsilon'_{min} = 1.7$ arcsec. This system is able to visualize and analyze low density high-speed flows[8]. Of particular interest is the visualization of the boundary layers associated with a continuum free jet expansion. This system was initially set up at the Measurement Science and Technology Branch of NASA-LaRC to characterize the high-speed flow of argon gas in HFG system.

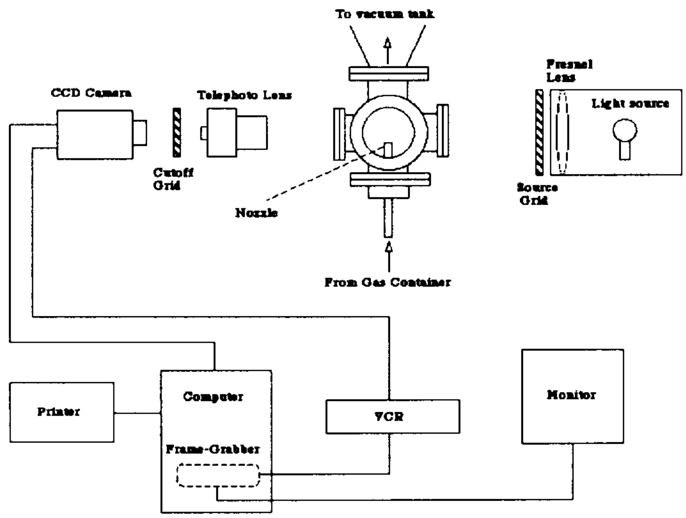


Figure 10. Diagram of the highly-sensitive Focusing Schlieren system incorporated into the High-Speed Flow Generator (HFG) at NASA LaRC.

Figures 11a and 11b show preliminary results of the application of this system to low density flowfields of argon gas. Figure 11 (a) is a background-subtracted VCR picture of the HFG system with a 5.0 mm nozzle. Free-jet expansion of argon gas (at 200 psig) into a 22 μTorr vacuum is visualized. The shock-front layers around a 12-mm diameter spherical barrier could be visualized, when it was placed in front of the nozzle (Figure 11b)

(a) (b)

Figure 11. (a) Background-subtracted VCR picture of the free-jet expansion of argon gas visualized by a high-sensitivity focusing schlieren system. Shock-front layers around the sphere are visualized with the Focusing Schlieren system (b).

Laser-Induced Fluorescence (LIF)

We have been set up a LIF experiment with an excimer-pumped tunable dye laser system that was transferred to the campus as a government furnished equipment from the MSTB, NASA LaRC (see Figure 12). This tunable dye laser (Lambda Physik, LPD 3002CES: Tuning range 332 nm - 860 nm) is pumped by an excimer laser (Lambda Physik, LPX 220I CC: Computer controlled, maximum energy of 200 mJ, pulse duration of 12 ns, 60 Hz) and is placed at Hampton University Advanced Propulsion Laboratory (APL). The APL facilities and project are supported by the Air Force Office of Scientific Research (AFOSR) for development of the Solar Thermal-Electric Propulsion (STEP) . The exhaust flow speed from the STEP is expected to reach several km/s providing an ideal testbed for the LIF technique. The dye laser system has produced an output of 11 mJ per pulse at 570 nm when Rhodamine 6G was used in a preliminary test run.

In order to diagnose hypersonic flows by LIF, we will use the Doppler shift and broadening of the selected fluorescence lines. Since the homogeneous bandwidth of 50 MHz of the laser is much less than the Doppler width (about several GHz) of the LIF lines of interest, one can scan across the and measure its shift and line width, from which velocities and temperatures of flows can be determined. This task is under way and the expected results will be reported later.

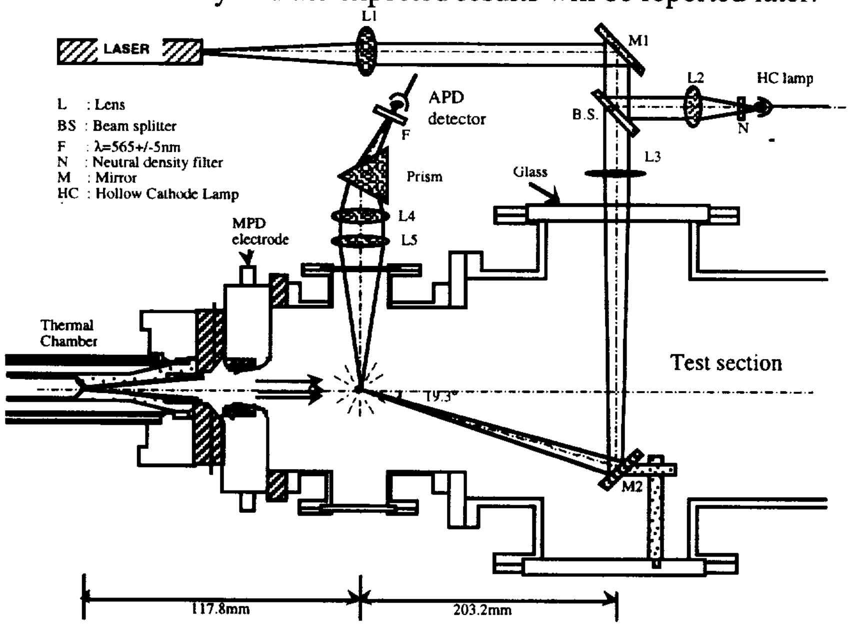


Figure 12. LIF Setup.

Conclusion

During this report period an EBF diagnostic system was set up and operated for the supersonic flow characterization. The quenching rate of N_2^+ emission by argon was studied. The low-density flowfield of the HFG system at MSTB, NASA LaRC visualized by the fluorescence images.

A very high sensitivity (less than 2 arcseconds) focusing schlieren system was also constructed and successfully applied to a low-density fast flow of argon gas in the HFG system. A LIF system using an excimer-pumped-dye laser has been installed and operated for the fast flow velocity measurements.

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3.2 Fiber Optic Sensors and Smart Structures

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Ms. Apriel K. Hodari
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Ms. Marinella Williams

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Mr. Raymond Bell
Ms. Grace Gregory
Ms. Tosha Hudson
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Daniel Lee
Rina Lau

3.2.1 Introduction

The research focus of this group is in the area of linear and nonlinear phenomena in optical fibers and their application to "Smart Materials and Structures". The research conducted under this grant involves the study of UV induced photorefractive effects in optical fibers with an emphasis on the use of the resulting Bragg reflection filters for generalized distributed sensing and, in particular, non-intrusive assessment of aerodynamic parameters. In addition, we have recently begun to do design studies involving interferometric fiber devices specifically oriented towards the fabrication of discrete, miniaturized fiber sensors and readouts, biomedical and chemical fiber optic sensors, and tunable diffractive optical devices as they relate to NASA's aerospace and 'mission to planet earth' applications. It has always been our aim to keep our 'Smart Materials' emphasis consistent with the original scope of the funded proposal and has been extended in scope with the aid of donated and leveraged resources.

Research Linkages with NASA:

During the past four years of the existence of the fiber optics effort we have been successful in establishing strong linkages between the fiber optics effort conducted under RCOP and several NASA field installations as well as Headquarters. These linkages include research for center funded grants for research from NASA Lewis, NASA Marshall, and a NASA Headquarters FAR grant as well as a Partnership Proposal through NASA Lewis form NASA Headquarters. Although most of our initial efforts were towards making contacts with NASA Langley by way of talks about, seminars concerning, and some technology transfer of our research by way of visits by several NASA scientists, we have not been able to create any partnerships or joint efforts with that particular NASA installation.

Technical Quality of the Research:

One of our projects entitled "Experimental and Theoretical Investigation of Phase Mask Defects Using Bragg Reflection Filters" involves the use of UV imaging techniques to study the detailed diffraction patterns generated by commercial phase masks in order to create a self-consistant model of these diffractive optics devices which can be used for accurate 'device fabrication prediction' and to push the fiber optic Bragg filter technology in a direction towards high powered, extended wavelength range, tunable writing devices. This study is further motivated by the present day costs associated with the creation of a single wavelength device and the usefulness of these devices in high energy flux, low coherence length Bragg grating writing systems. A second project is entitled "The Construction of a High

Resolution Wavelength Standard for the Writing of Transverse Holographic Gratings" and involves the construction of a computer controlled double interferometer comparator for use as a writing wavelength standard. This is a CW oriented device whose application to highly accurate Bragg filter spacings could lead to standardized distributed fiber sensor networks. There is no current method for creating evenly spaced Bragg reflection filters. This patented device has recently been extended to include pulsed laser sources. Both of these projects are high profile projects which have numerous applications in varied disciplines. The work being done in this area continues to have profound implications for advances in aerospace (aerostructures intelligent enough to do self-monitoring and save millions of lives), telecommunications (high volume active and passive switches and splitters for wavelength division multiplexing), medicine (artificial nerves at density levels approaching that of the human nervous system), etc. In addition, there are six other distinct fiber optics efforts underway in the 'Fiber Optics Sensors and Smart Structures' area in RCOP which have been designed for Ph.D. level studies and which can easily lead to technology transfer.

3.2.2 Accomplishments

- We have completed the building of a prototype for multiple sensor fabrication as shown in the schematic of Figure 13a. This prototype consists of a high resolution, automated writing system which contains a double interferometer setup (one visible, as shown in the photograph of Figure 13b, and the other UV).
- We demonstrated the capability of verifying the interference fringe spacings in fibers, and therefore Bragg resonance prediction, by using D-type fibers in conjunction with the photographic technique of "grating-fiber image reproduction". As an experimental aside, this work has lead to the design of a new tunable writing device and to a deeper understanding of the physics surrounding phase mask design and fabrication. In, addition See Figure 14a for the principle of the technique.
- We currently have fabricated several V-grooves fixtures for use in aerodynamic sheer stress and fluid pressure measurements. D-fibers with Bragg gratings have been placed into the grooved regions and covered with a thin layer of epoxy so as to appear to be a part of the normal, smooth surface of the fixtures. Techniques for enhancing the sensitivity devices have been developed and are to be used for these and other purposes. In addition, we have set up simulated high flow conditions, using compressed air with regulators and a fixture for controlled but variable flows across the surfaces of these same sensor embedded units. Data from these experiments is forthcoming.
- We have obtained preliminary evidence that these sensors may have reasonable responses and we are therefore setting up more elaborate measures to quantify and possibly enhance their sensitivities. We also have several simple designs for optimizing the response of the sensors for their present configurations. Figures 17 and 18 illustrate sensor enhancement using matched Bragg filters. Sensitivity enhancements also include the choice of retrofit materials in which the sensors are embedded and a possible amplification of the strain transfer to the D-fiber sensors using gradation of material.
- We have preliminarily set up a Bragg grating calibration cantilever beam where we have placed a parallel commercial strain gauge. We are able to see both the wavelength shift due to straining Bragg units and the commercial strain gauges. This allowed us to generate strain vs. wavelength calibration curves for the fiber grating sensors. This work was started as a summer project and the building of the experimental setup and acquisition of the data were done by a Sharp Plus high school student.

At present, we have developed a miniature FO spectrum analyzer for readout, verification, and characterization of distributed Bragg filters within a given fiber unit. This verification method involves the device shown in figure 15a. Its preliminary response to a single frequency, actively stabilized He-Ne laser is shown in the bottom of figure 15a. Figure 15b shows the completed Bragg filter SMFOSA unit for sensor characterization. We are considering the use of a newly marketed miniature spectrometer as a second possible Bragg readout device. Several key modifications to this microspectrometer will be necessary due to the fact that the device is presently limited to multimode fiber inputs and resolutions of 7nm. We have contacted the company concerning the possibility of doing the research that will be necessary to convert the device to a high resolution spectroscopic unit that can accomodate a single mode fiber input. We are presently using the illumination of a reflection filter with an SLD (Superluminescent Laser Diode) light source and detecting the back reflected signals at the Bragg wavelengths. These signals are then further characterized in linewidth and reflection amplitude using a commercial spectrum analyzer (HP 70004A and HP 71451A). In addition, a tunable laser with wavelength scanning capabilities is also used. In our case we use a Ti:Sapphire laser set up to scan from 780 to 870nm.

Technology Transfer Strategies:
At the present time, several technologies are being considered for technology transfer through industrial and government contacts. A portfolio of patents and patent disclosures is being built up along with an Intellectual Property policy on the part of the University in a effort to enter into mutually beneficial licensing agreements with organizations that can exert a market push for these various technologies. An example of such an effort would include a recent non-disclosure agreement between Hampton University and Coherent, Inc.

Performance in Research Output:
Our findings, noted in a recently reworked paper entitled "Observations of Phase Mask Defects Using Grating-Fiber Image Reproduction" by D. R. Lyons, J. V. Lindesay, Z. Ndlela, and H. R. Lee have led to a patent disclosure and suggest the possibility of the development of a new class of tunable diffractive devices. In addition, we have recently received two patents. The first is entitled "Method of and Apparatus for Calibrating Precisely Spaced Multiple Transverse Holographic Gratings in Optical Fibers" by D. R. Lyons and Zolili Ndlela. This apparatus, though not developed primarily for smart structures purposes, is projected to greatly impact the ability to create high definition distributed sensing systems. The second patent is "Instrumented Patch for Repair of Fatigue Damaged or Sensitive Structure", by D. R. Lyons, S. M. Reich, and P. Shyprykevich. This patent involves the development of retrofit sensor technology for aging aircraft and for other structures where long term monitoring of deterioration is crucial. In addition, we presented a paper at an international conference which was subsequently published in the proceedings of the "ICO 17 Optics for Science and Technology". The primary goals and current
accomplishments of the 'Fiber Optic Sensors and Smart Structures' research group demonstrate how fiber optic sensors can be fabricated for incorporation into aerospace structures and environments for feedback control and for the purpose of monitoring parameters such as temperature and pressure. In addition, we look forward to the eventual realization of an array of such sensors deployed in various structural components and in various remote or inaccessible environments to perform health or environmental monitoring functions in a routine fashion.

Student Performance:
All of my students have given talks and presentations. Two of them, Mr. Kenneth Samuel and Mr. Hyung Lee, have given several talks and technology demonstrations and four others have received additional grants for graduate study. These are several of their accomplishments: "Strain-Optic Effect for UV-Induced Bragg Gratings", NASA-URC Conference, North Carolina A&T (Spring 1996); "Fiber Optic Bragg Grating Strain Sensor Research", Virginia Space Grant Consortium Fellowship Awards for 1994-1996. Three other students in my group have also received the same award. At the present time, there are 7 graduate and 3 undergraduate students involved in fiber optic sensors related research. See Figure 23 'Group' picture.

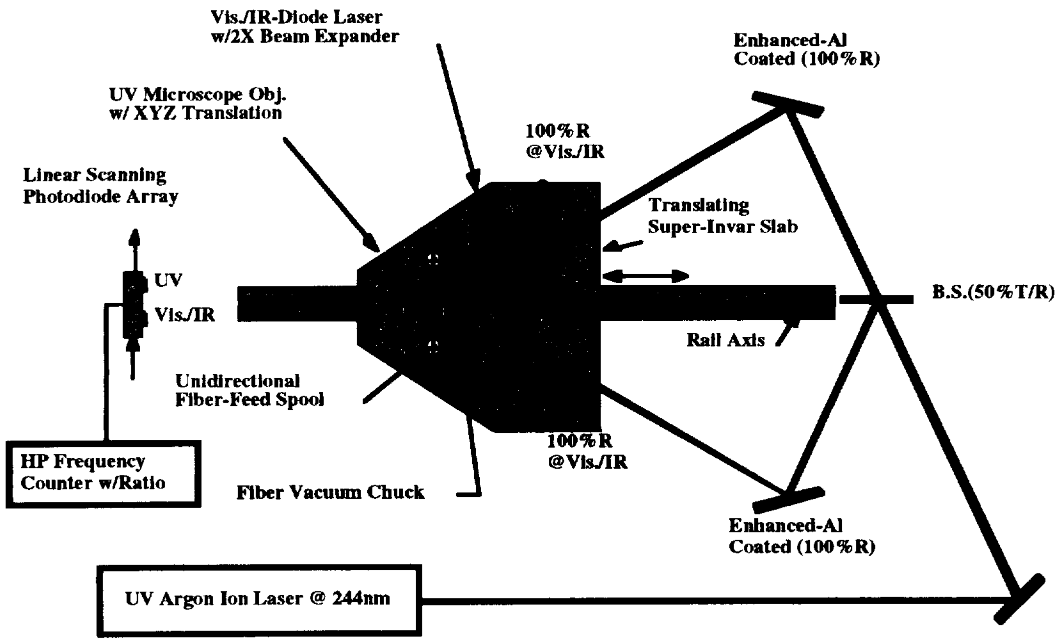


Figure 13. Multi-sensor writing prototype based upon a double interferometer wavelength comparator.

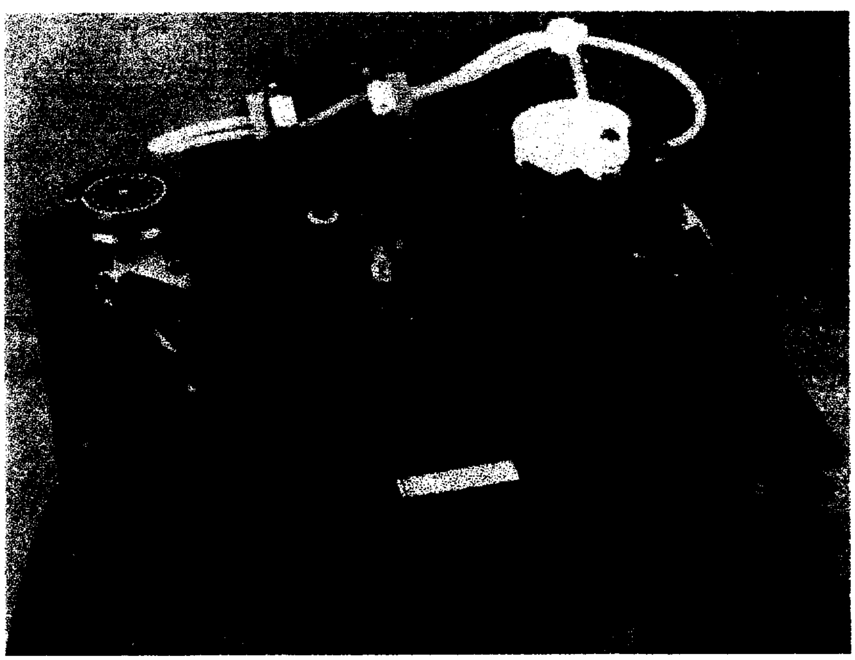


Figure 14. Bragg reflection filter wavelength comparator or standard.

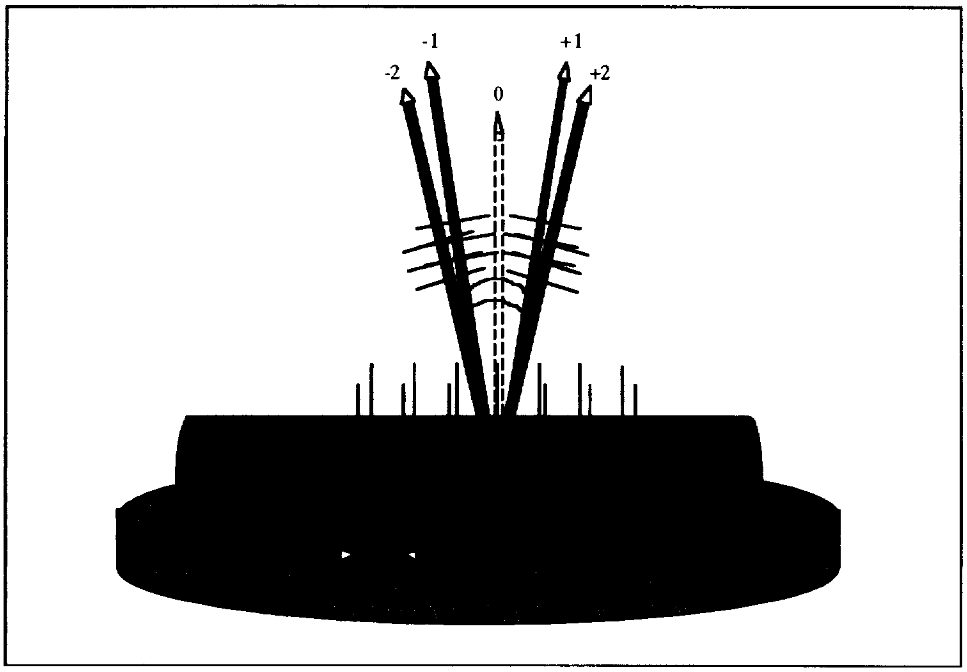


Figure 15. 1st and 2nd order diffracted beams generated by a phase mask.

Figure 16.	Phase Mask	Phase Mask	Transverse Holographic
	Period = 1.059mm	Period = 0.566mm	q = 25 degrees

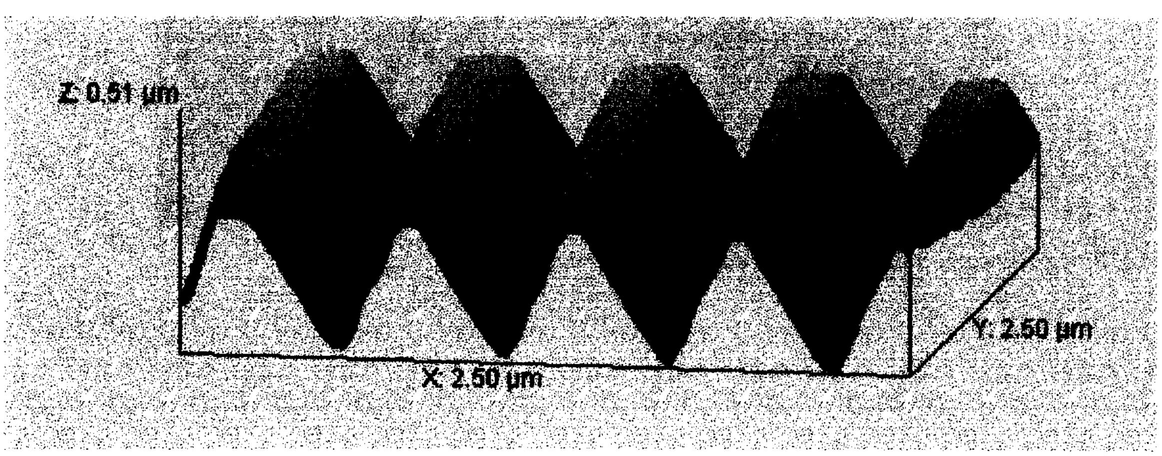


Figure 17. An Atomic Force Microscope (AFM) Scan of the .566 ptich phase mask.

Snell's law implies:

$\varphi_1 = \mathrm{Sin}^{-1}(n_r \cos(\varphi_w))$

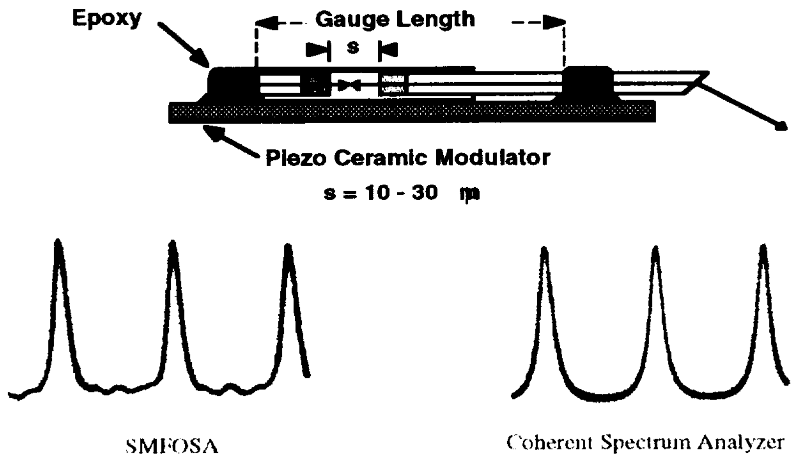
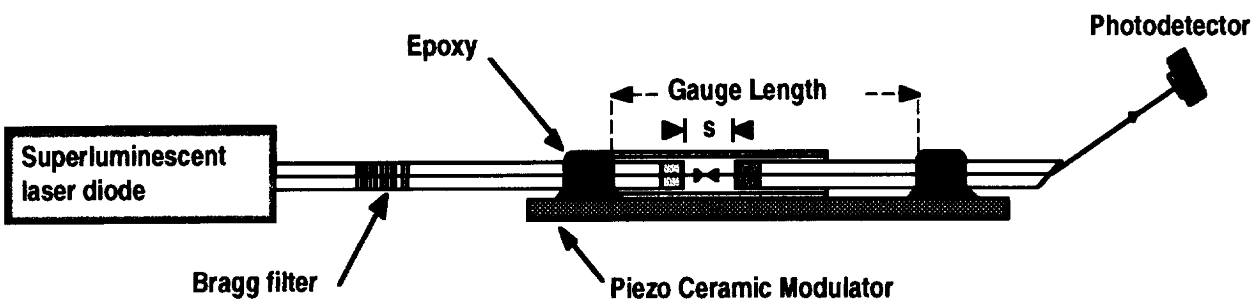


Figure 18. Single mode fiber optic spectrum analyzer for use as a compact Bragg grating readout.



$s = 10 - 30\ \mu m$, $R_1 = R_2 = (50 - 90\%$ **Reflectivity @ 633nm)**

Figure 19. Bragg grating detection using in-house constructed SMFOSA.

US005552882A

United States Patent [19]

Lyons et al.

[11] **Patent Number:** **5,552,882**

[45] **Date of Patent:** **Sep. 3, 1996**

[54] **METHODS OF AND APPARATUS FOR CALIBRATING PRECISELY SPACED MULTIPLE TRANSVERSE HOLOGRAPHIC GRATINGS IN OPTICAL FIBERS**

[76] Inventors: Donald R. Lyons, 180 Richmond Run, Yorktown, Va. 23693; [illegible] U. [illegible], 8528 [illegible] Eagle Way, Fair Oaks, Calif. 95628

[21] Appl. No.: 413,979

[22] Filed: Mar. 28, 1995

[51] Int. Cl.^{6} G01N 21/84; G01B 9/021; G02B 6/34

[52] U.S. Cl. 356/73.1; 359/34; 359/35

[58] Field of Search 356/73.1; 359/34, 359/35; 385/37

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Primary Examiner—Vincent P. McGraw
Attorney, Agent, or Firm—Millen, White, Zelano, & Branigan, P.C.

[57] **ABSTRACT**

A Bragg reflection filter wavemeter is used to measure transverse holographic gratings and optical fibers and utilizes a first interferometer which is always fixed with respect to the optical fiber and a second adjustable interferometer. The optical fiber and first interferometer are mounted on a translating support while the second interferometer includes a pair of angularly adjustable mirrors for changing the angle at which the object and reference beams thereof intersect the fiber. Since the fiber is mounted on a movable support, the position of the support can be continually adjustable so that the reference and object beams always intersect the fiber at the same point, regardless of the angle assumed by the reflecting mirrors. The resulting interference patterns are projected by an objective lens to the far field in which a linear scanning, photodiode array is moved. The photodiode array includes a first photodiode which is sensitive only to the interference patterns from the first laser beam and a second photodiode sensitive to the interference patterns from the second laser beam. The photodiodes are connected to a counter which provides ratios of interference line counts which are then multiplied by wavelength to provide precise modulation spacings so as to establish wavelength standards.

21 Claims, 2 Drawing Sheets

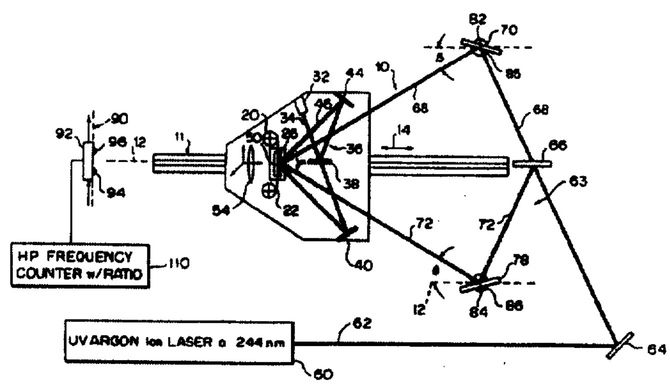

Figure 20. High volume Bragg grating wavelength comparator. Note: Notification of issuance was given in May 1996.

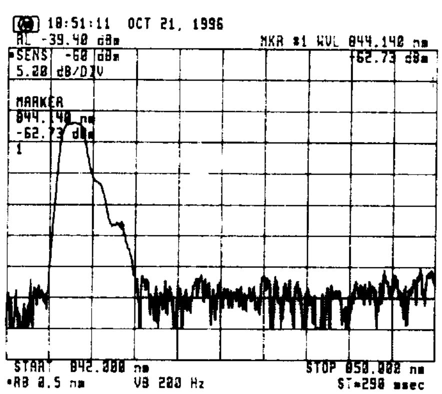

Figure 21. Identical unperturbed Bragg gratings

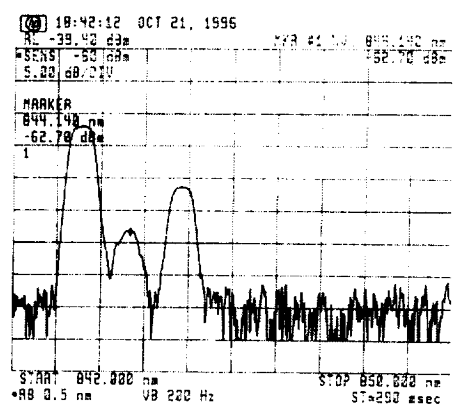

Figure 22. Identical perturbed Bragg gratingsfor resonance enhance. for resonance enhancement.

Figure 23. The Fiber Optic Sensors and Smart Structrues Group

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3.3 Nonlinear Optical Materials and Devices

3.3.1 Photorefractive Materials for Holographic Data Storage

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Mr. Michael Lucas
Mr. Marcus McTeer

3.3.1.1 Introduction

The NASA Space Technology Enterprise is engaged in developing technology to reduce the cost of access to space. One method to achieve this goal is to use advanced technologies for miniaturization of scientific equipment. Photorefractive materials are becoming an attractive alternative media for ultra-high density data storage devices.[1-3] The objective of our research is to understand the microscopic physical processes that determine the photorefractive properties of these materials.

The goal of this group is to develop a state-of-the-art spectroscopy laboratory for the study of nonlinear optical properties of materials such as single crystal oxides, polymers, organic thin films and multiple quantum well devices. To date, we have developed the folowing capabilities:

- CW laser spectroscopy in the wavelength range 400 nm to 1000 nm with a resolution of 10 Mhz
- Pulsed laser spectroscopy in the wavelength range 450 nm to 1000 nm with pulse widths of 70 ps to 70 fs with a variable repetition rate
- Polarized absorption spectroscopy in the wavelength range 175 nm to 3300 nm
- Pump-probe photoinduced absorption pulsed and cw
- Single crystal growth of oxide single crystals up to 1600 °C

Optical data storage technology has dramatically increased the volume and speed that information can be manipulated. These technologies have been dominated by magnetic tape, magneto-optical and compact disc data storage devices.

A relatively new technique for dramatically increasing data storage capacity is to store data holographically. A typical architecture for holographic data storage is shown in Figure 24. In this system, digital information is encoded in the form of large data arrays (two dimensional array of bright and dark pixels) and addressed optically using a spatial light modulator (SLM). The page can then be stored in the form of a hologram in a photorefractive (PR) material. Thousands of pages can be stored in the same volume of the PR material using angular multiplexing (storing holograms at different angles).[1], [2] Recent calculations place the theoretical storage density on the order of Terabits per cubic centimeter (1×10^{12} bits/cm^3) which is several orders of magnitude above current technologies.[3] Another advantage is that the bits are stored in parallel which reduces the access time and should have significant impact on the speed of PR devices relative to serial data storage techniques. Some estimates predict that *"the Encyclopedia Bratannica could be stored in the volume of a dime."* [1]

Due to its large optical nonlinearities, one material of particular interest is $BaTiO_3$. In an effort to improve the speed and diffraction efficiency of $BaTiO_3$, several groups have studied the influence of ionic dopants on its photorefractive properties. These dopants have included iron[4], cerium[5], cobalt[6] and rhodium[7],[8].

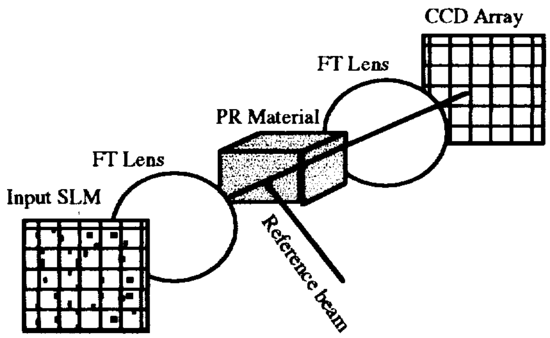

Figure 24. Holographic data storage system.

Dr. Mark Garrett and co-workers [6], [7], [8] determined that rhodium doped $BaTiO_3$, commonly referred to as *"Blue Barium Titanate,"* has the fastest response time and largest diffraction efficiency material to date.

We have entered into a collaboration with Dr. Garrett and Deltronic Crystal Industries, Inc. to perform a detailed analysis of the photorefractive properties of blue barium titanate. They have already supplied us with samples. This work comprises the Ph.D. dissertation research for Ms. Apriel Hodari.

3.3.1.2 Wave-Mixing Spectroscopy of Photorefractive Materials

We are performing cw and pulsed photorefractive measurements on a unique set of $BaTiO_3$ crystals that were fabricated at Deltronic Crystal Industries, Inc. The cw measurements, as well as, a portion of the ultra-fast measurements comprise the dissertation research for Ms. Apriel Hodari. The samples include pure $BaTiO_3$ and $BaTiO_3$ doped with rhodium.[4-6] $BaTiO_3$ samples that are placed in reduced oxygen partial pressures at elevated temperatures exhibit n-type photoconductivity and have a significant increase in the photorefractive speed, a key parameter for photorefractive devices. These samples have also been reduced to further increase the n type conductivity.

The experiments employed to study photorefractive gratings (PRG), photochromic gratings (PCG) and photoinduced absorption (PA) will determine microscopic charge transport parameters such as carrier densities, mobilities, etc., are:

Experimental Goals

1. polarized absorption measurements
2. cw measurements of PRG, PCG and PA response times and steady state two wave mixing gain as a function of
    - grating spacing
    - writing beam wavelength (VIS to NIR)
    - writing beam intensity
3. ultra-fast measurements of PRG, PCG and PA response times and wave mixing gain as function of
    - grating spacing
    - fluence
    - repetition rate

3.3.1.3 Experimental Setup

The system used to study the dynamics of PRG, PCG and PA effects under cw or pulsed illumination is shown in Figure 25. There are four optical delay lines dl0, dl1, dl2 and dl3 which are adjusted such that the three beams arrive at the crystal simultaneously. The mirrors m1, m2 and m3 are then positioned such that PCG, PRG or PA can be studied. The detection system uses a high speed digitizing oscilloscope (ultra-fast measurements) or a 16 bit A-D board (cw measurements) for data acquisition and a computer for control of the experiment and storage of the experimental data.

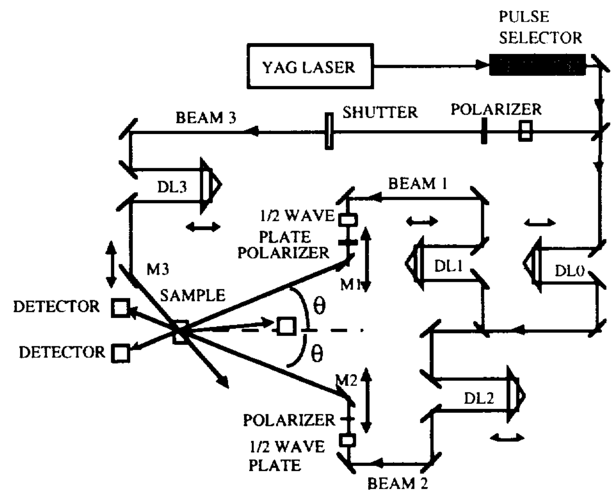

Figure 25. Optical system used to measure picosecond dynamics of PRG, PCG and PA as a function of grating vector.

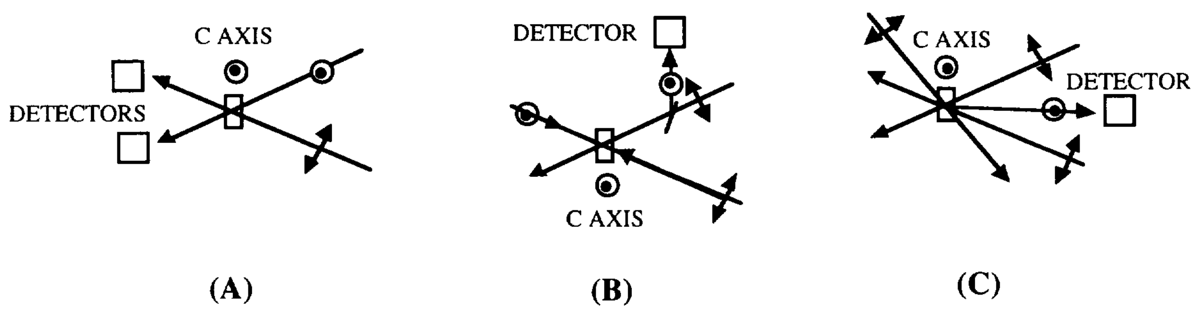

Figure 26 Schematic diagram of the different configurations possible using the system shown in Figure 25. The beam configurations are shown for (a) PA, (b) PCG and (c) PRG measurements.

Photoinduced Absorption Measurements

The specific optical beam configuration for studying photoinduced absorption is shown in Figure 26a. For this case, beam 3 is blocked by an optical shutter. The half wave plate and the polarizer in the path of beam 1 are adjusted such that the fluence is small and the polarization of the wave entering the crystal is parallel to the c axis. This beam is used as the probe beam. The half wave plate and the polarizer in the path of beam 2 are adjusted such that the wave entering the crystal can be either parallel or perpendicular to the c axis. The fluence is adjusted by rotating the half wave plate.

The measurements involve adjusting the optical delay line DL1 such the probe pulse enters the crystal at specified time delays relative to the pump beam 2. The intensities are recorded as a function of time delay and pump fluence.

Photochromic Grating Measurements

The beam configuration for studying PCG is shown in Figure 26b. In this case, beam 3 is used as the probe and beams 1 and 2 are used to write the gratings. The half wave plate and polarizer in the path of beam 3 is used to adjust the polarization and the fluence of the probe beam. Mirrors m1 and m2 are mounted on a precision translator that allows accurate positioning of the writing beams. Using this method, the writing beam angle of incidence theta can be smoothly varied over a wide range of angles with accurate repeatability. The half wave plates and polarizes in the paths of the writing beams can be used to fix the fluence and polarization of each beam. Since the waves intersect in the x-y plane of the crystal beam coupling and anisotropy self diffraction is not allowed for ordinary polarized waves.

However, if extraordinary waves are used there is a specific set of angles in which high order anisotropy self diffraction. Since these angles are easily calculated[8] they can be avoided.

Mirror m3 is positioned along a precision translation rail such that the probe beam propagates anti-parallel to writing beam 2. A beam splitter placed in the path of beam 1 allows measurement of the diffraction due to the free carrier grating. As stated earlier, diffraction due to electrooptic effects is forbidden in this specific geometry for 4mm symmetry crystals.

Photorefractive Grating Measurements

The configuration for observing PRG is shown in Figure 26c. It is similar to the configuration for studying PCG except that phase matching requires that the probe beam and the diffracted beam to be at different angles from the writing beams. This is advantageous in that the PCG and the PRG diffraction can be easily separated and studied independently. Again, mirrors m1 and m2 move along a precision track to allow several writing angles θ. Since this configuration requires anisotropic diffraction for PRG, the probe and diffracted beam are orthogonally polarized.

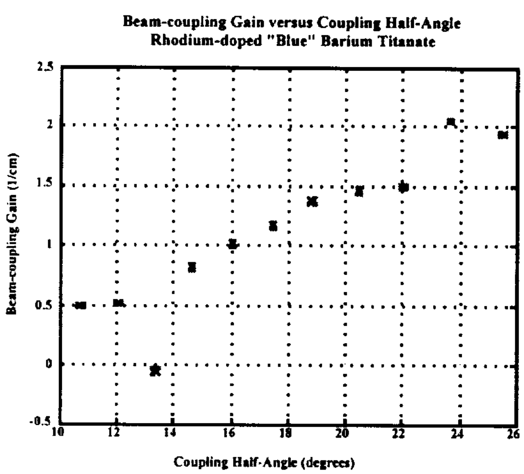

Figure 27. Measurements of the two wave mixing gain as a function of crossing angle in $BaTiO_3$ doped with 400 ppm Rh.

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3.3.2 Organic Thin Film Deposition

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Dr. Satish C. Mathur

Undergraduate Students
Ms. Shontell Credit

Graduate Students
Ms. Florence Etop
Mr. Melvin Spurlock
Mr. Kengil Seo

Introduction

The forthcoming availability of single-mode microcavities at optical frequencies will lead to a new situation in quantum electronics. Now we can combine the physics and technology of spontaneous emission with the capability of single mode microcavities at optical frequencies, where spontaneous emission is important. This combination is fundamentally a new regime in quantum electronics. A new type of device is a single-mode light-emitting-diode (SM-LED), which can have many of the favorable coherence properties of lasers while being a more reliable and thresholdless device. It has been suggested that by doping the photonic crystal, it is possible to create high-Q electromagnetic cavities whose modal volume is less than a half-wavelength cubed. These doped photonic crystals would be similar to metallic microwave cavities, except that they will be usable at higher frequencies, where metal walls would become lossy. Photonic Bandgap Structures (PBS) have recently emerged as an exciting opportunity for new and improved devices covering the electromagnetic spectrum from microwaves to the optical frequencies.

Objectives

Main objective of the work are fabrication of single mode - light emitting diode (SM - LED) and vision protection shield against high intensity lasers.

Background

Three-dimensional periodic dielectric structures can have photonic bandgaps - frequency regions in which propagating electromagnetic waves are forbidden in every direction. Electromagnetic waves inside the photonic band-gaps have no propagating modes, which is quite analogous to the electron waves inside conventional electronic energy band gaps. The three dimensional periodic dielectric structures have been called *Photonic Crystals*. Various photonic crystal structures such as face centered cubic (fcc), diamond, and simple cubic (sc) have been shown to have photonic bands. The experimental work reported so far is at microwave frequencies. Other studies are either theoretical or are concerned with computer simulation.

At optical frequencies of the spectrum PBS can provide sensor and vision protection against high-intensity laser beams. PBS materials exclude all electromagnetic radiation over a wide range of frequencies. Radiation within the band gap will be reflected. In order to reject high intensity radiation, non-linear materials with an intensity dependent refractive index are required. The combination of the principles of non-linear optical materials and PBS concept, suggest that one can create one-dimensional photonic band gaps which may exclude electromagnetic radiation only when the light intensity is high. Periodic 1D and 2D systems composed of periodic arrays of dielectric scatterers have been examined theoretically and at microwave frequencies. A photonic bandedge laser using a multilayer structure has also been proposed.

The forthcoming availability of single-mode microcavities at optical frequencies will lead to a new situation in quantum electronics. Of course microwave cavities that contain a single electromagnetic mode have been known for a long time. At microwave frequencies, however, spontaneous emission of electromagnetic radiation is a weak and unimportant process. At optical frequencies spontaneous emission comes into its own. Now we can combine the physics and technology of spontaneous emission with the capability for single-mode microcavities at optical frequencies, where spontaneous emission is important. This combination is fundamental a new regime in quantum electronics. Progress in electromagnetic microcavities permits all the spontaneous emission of an LED to be funneled into a single electromagnetic mode.

Work Plan

The work involves fabrication of Photonic Bandgap Structures using organic materials and an ORGANIC MOLECULAR BEAM DEPOSITION (OMBD) technique, coupled with interferrometric laser ablation technique and introduction of connectivity of one phase. For materials synthesis and other materials related work such as ultra purification etc. we have a collaboration with the Materials Research Center of Norfolk State University. Our emphasis is on the Photonic Bandgap Engineering for fabricating Optical devices referred above. An expected spinoff of the work may be development of Organic Quantum wells (OQW) and Organic Multiple Quantum Wells (OMQW).

3.4 LASER MATERIAL DEVELOPMENT GROUP

Investigator: Dr. Uwe Hömmerich

Post Doctoral Fellow
Dr. Xingkun Wu

Graduate Students
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Ms. Renita White
Mr. Myo Thaik

Undergraduate Students
Mr. Terrence Robinson-Brown
Mr. Derrick Whitehurst

3.4.1 Program Overview

The strategic focus of our work is the development, characterization, and device testing of new optical materials which are of interest as light emitting diodes (LED's), optical amplifiers, and solid-state lasers. The main research emphasis during the time period covered by this report was on material preparation, optical spectroscopy, theoretical modeling, as well as device demonstration of rare earth and/or transition metal ion doped solids. The material preparation was carried out in cooperative research programs with Universities and Industrial Partners. Most optical materials under investigation were targeted towards the development of solid-state lasers for NASA's remote sensing program.

3.4.2 Development of a tunable mid-infrared (2-4μm) laser material based on Cr doped II-VI semiconductors

Partner: Brimrose Corporation of America

Summary:

The development of tunable solid-state lasers operating in the mid-infrared wavelength region (2-4 μm) is of significant current interest for applications in remote sensing, medicine, and scientific research [1]. Specifically, NASA is interested in remote sensing "greenhouse" gases including carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO), which have strong absorption bands between 2 and 3.5 μm.

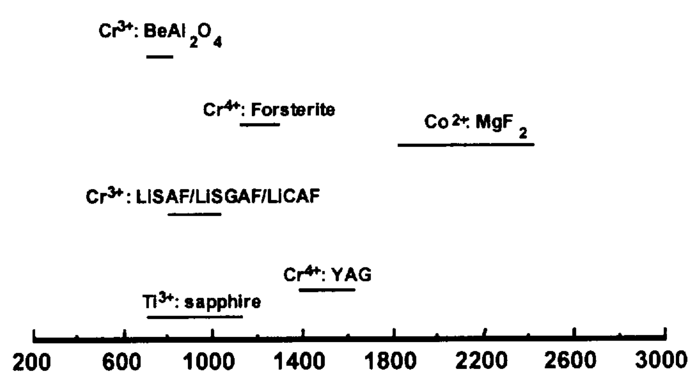

Figure 28. Tuning ranges of commercial transition metal ion lasers [3]. Efficient transition metal lasers operating in the mid-infrared region have not yet been developed.

In recent years, optical parametric oscillators (OPO's) have become available providing tunable output over a wide range in the infrared and mid-infrared spectral region. Their complex nonlinear-optical schemes, however, require high pumping powers and stringent demands on alignment. In addition, OPO's have poor beam quality, lack compactness and robustness.

An attractive alternative technology is the development of tunable solid-state lasers based on transition metal doped solids [2]. In these systems, absorption and emission of light arise from electronic transitions between internal energy levels of 3d transition metal ions. Transition metal lasers are not as widely tunable as OPO's, however, when employing a diode-laser pump excitation scheme, highly efficient and compact systems can be designed. Examples of commercial transition metal lasers are Cr^{3+}: $BeAl_2O_4$ (Alexandrite), Ti^{3+}: Sapphire, Cr^{3+}: LISAF/LICAF, Co^{2+}: MgF_2, and the recently discovered laser materials Cr^{4+}: forsterite and Cr^{4+}: YAG. Co^{2+}: MgF_2 shows tunable laser emission between 1.8 - 2.4 μm, but its performance and mode of operation is severely limited by strong nonradiative decay at room temperature. Based on lifetime data, the quantum efficiency has been estimated to be less than 3%. In general, the probability for non-radiative decay via multi-phonon relaxation increases with decreasing energy gap between ground and excited state, because less phonons are necessary to bridge the gap. Therefore, efficient transition metal ion lasers beyond ~1.6 μm are rare (see Figure 28).

A promising approach to overcome the low quantum efficiencies of transition metal lasers operating in the infrared region was recently suggested by researchers at Lawrence Livermore Laboratories. A new class of mid-infrared laser materials based on transition metal doped zinc chalcogenides was proposed [4]. Feasibility of this approach was demonstrated by the observation of laser activity at 2350 nm from Cr^{2+}: ZnS and Cr^{2+}: ZnSe. These first studies have shown slope efficiencies around 20% under non-optimum conditions. A systematic study on evaluating the full potential of Cr^{2+} doped II-VI semiconductors as solid-state laser materials, however, has not yet been performed.

We are currently engaged in the first comprehensive study on the growth, spectroscopy and laser behavior of Cr^{2+} doped $Cd_{1-x}Mn_xTe$ ($0<x<0.7$). The overall goal of this effort is to develop a laser-diode pumped, tunable, solid-state laser material for the 2-4 μm wavelength region. Our partner in the crystal growth of the investigated materials is Brimrose Corporation of America. $Cd_{1-x}Mn_xTe$ crystals are chosen as potential new host materials for Cr^{2+} ions because they are easier to growth than ZnS and ZnSe. The low melting point (1070 - 1100 C) and the nature of the $Cd_{1-x}Mn_xTe$ phase diagram allows the growths of large crystals (up to 1.5 inch diameter) with good compositional homogeneity using a modified Bridgman technique. Moreover, the ternary nature of $Cd_{1-x}Mn_xTe$ allows variations in crystal composition and tuning of the optical properties of Cr^{2+} ions.

Jointly with Brimrose, we succeeded in preparing Cr^{2+} doped $Cd_{0.85}Mn_{0.15}Te$ and performed a preliminary spectroscopic evaluation of this material for solid-state laser applications. A survey of the room-temperature absorption and emission spectra of Cr doped $Cd_{0.85}Mn_{0.15}Te$ is shown in Figure 29. The absorption spectrum exhibits a broad-band centered at 1900 nm which is assigned to the spin-allowed ${}^5T_2 \rightarrow {}^5E$ transition of tetrahedrally coordinated Cr^{2+} ions ($3d^4$ electronic configuration). A mid-infrared absorption band centered near 1800-1900 nm is a characteristic "fingerprint" for Cr^{2+} ions in II-VI semiconductors. Since no energetically higher lying quintet states exist, all other intra-3d transitions of Cr^{2+} are spin-forbidden and no significant losses due to excited state absorption are anticipated. The emission spectrum of Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ excited at 1900 nm shows a broad-band centered at 2225 nm with a room-temperature lifetime of 1.4 μs. Based on temperature dependent lifetime measurements we estimated the emission quantum efficiency to be approximately 38%. A summary of the spectroscopic properties of Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ and a comparison to the commercial laser material Ti: Sapphire is shown in Table I. It can be noticed that both system are characterized by large absorption and emission cross sections, short lifetimes, relatively high quantum efficiencies, and broad luminescence bands. Table I shows that the spectroscopy of Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ compares very favorable with Ti^{3+}: sapphire. Therefore, similar modes of operation as demonstrated for the commercial Ti^{3+}: sapphire laser can be expected for Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$.

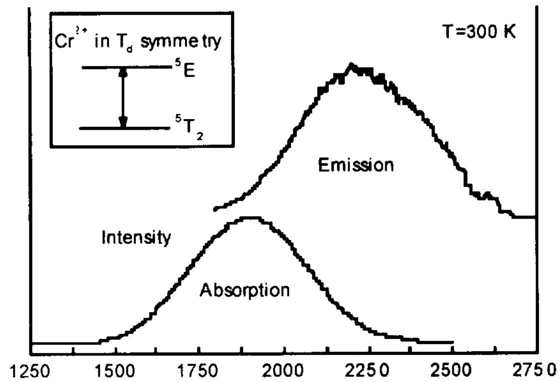

Figure 29. Mid-infrared absorption and emission spectra of Cr^{2+}: $Cd_{0.85}MnTe$ at room temperature. The insert shows the relevant energy levels of tetrahedrally coordinated Cr^{2+} ions ($3d^4$ electronic configuration).

Based on the promising spectroscopy of Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$, we have started preliminary laser experiments. Recently, we were able to demonstrate for the first time mid-IR laser operation from Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ at room temperature using a H_2-Raman shifted Nd: YAG laser as excitation source. The laser crystal was a hand polished, uncoated, 3-4 mm thick sample placed in a simple end-pumped laser cavity consisting of a flat high reflector (R>99% @ 2350 nm) and a curved output coupler (R=95% @ 2350nm). The experimental setup of the new Cr^{2+} laser is shown in Figure 30. Laser activity centered at 2525 nm was achieved with a threshold pump energy of 4mJ (Figure 31). Under less than optimum conditions the slope efficiency was measured to be 5.5%. A higher efficiency of the Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ laser is expected after optimization of crystal preparation and cavity design. More detailed studies on the optical and laser properties of Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ as a function of Cr concentration and growth parameters are currently in progress.

	Ti^{3+}: Sapphire	Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$
Absorption cross-section [cm^2]	$2x10^{-20}$	$4x10^{-19}$ (lower limit)
Emission peak [nm]	800	2250
Emission bandwidth [nm]	300	450
Emission cross-section (σ)[cm^2]	$4x10^{-19}$	$2x10^{-18}$
Lifetime radiative [μs]	3.8	3.7
Lifetime (τ) at 300K [μs]	3.2	1.4
Quantum Efficiency [%]	83	38
$\sigma\tau$ [$s\ cm^2$]	$1.4x10^{-24}$	$3x10^{-24}$

Table 1. Comparison of the spectroscopic data of Ti^{3+}: Sapphire and Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$

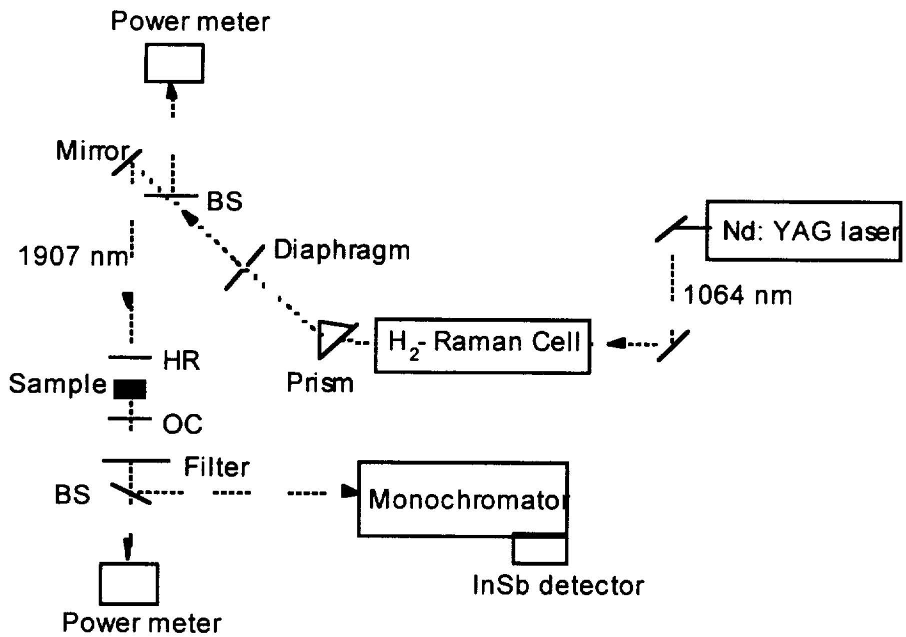

Figure 30. Experimental setup for testing the performance of the new Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ laser. (BS: beam splitter, HR: high reflector, OC: output coupler)

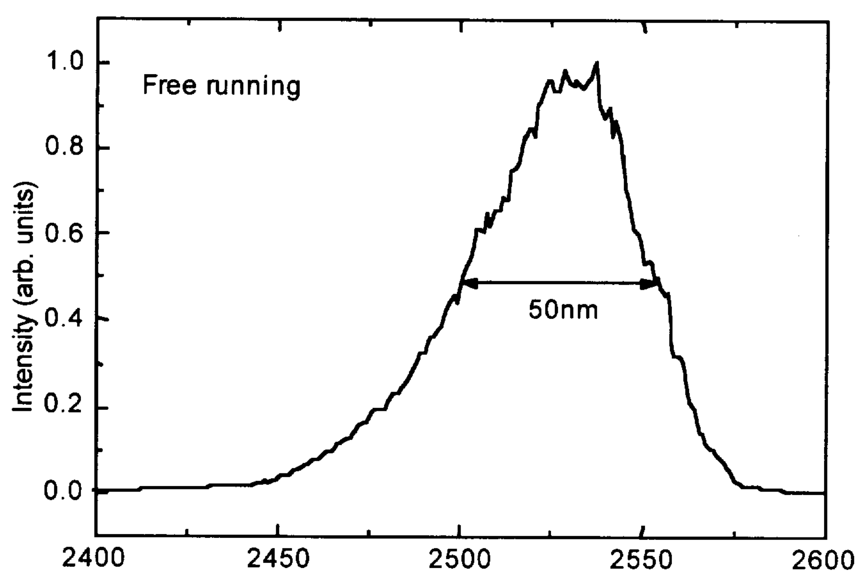

Figure 31. Free running spectrum of the Cr^{2+}: $Cd_{0.85}Mn_{0.15}Te$ laser at room temperature. The laser activity was centered at 2510 nm with a bandwidth of 50 nm (FWHM).

3.4.3 Optical characterization of rare earth doped wide band-gap semiconductors

Partners:
Spire Corporation, University of Florida, Hughes Research Laboratories, Army Research Office

Summary:
Rare earth doped semiconductors have received world wide attention because of possible applications in optical communications and flat panel displays. These systems exhibit extremely temperature stable luminescence which is nearly independent of the specific semiconductor host. Rare earth doped semiconductors offer the prospect to develop novel electroluminescence devices which combine the electronic properties of semiconductors with the unique luminescence features of rare earth ions.

Our investigations in this research area focus on the rare earth ion Er^{3+}, because it exhibits luminescence at 1.54µm which overlaps the minimum loss region of silica-based fibers used in optical communications. A major problem hampering the advancement of rare earth doped semiconductor devices has been the poor luminescence efficiency at room temperature. Recent studies have shown that the Er^{3+} luminescence efficiency is strongly related to the band-gap energy of the semiconductor host. It was found that semiconductors with larger band-gap energy, exhibit stronger luminescence at room temperature. Consequently, research efforts have shifted towards studying Er^{3+} doped into wide band-gap semiconductors.

We are engaged in a comprehensive study of the optical properties of Er^{3+} doped Si based and III-nitride wide band-gap semiconductors. Our main objectives are to assess the potential of the materials for opto-electronic applications and to gain insight in the microscopic physical processes that determine the Er^{3+} luminescence properties. The obtained results are used to provide feedback to the material optimization. The overall goal of this effort is to develop compact and efficient electroluminescence devices for applications in optical communications.

The development of a Si based emitter is of enormous technological interest because it allows the integration of electronic and optical devices using the mature Si technology. Er^{3+} doped Si has been studied for many years but the achieved Er^{3+} luminescence efficiency at room temperature was low. Porous Si is a new Si based semiconductor which has a band-gap ranging from 2-2.5eV. This relatively large band-gap makes porous Si very attractive as a host material for Er^{3+} ions. In collaboration with Spire Corporation, we have performed the first detailed spectroscopic study of Er doped porous Si and evaluate its potential as an efficient 1.54 µm emitter for optical communications.

The temperature dependent photoluminescence (PL) spectra of Er doped porous Si are shown in Figure 32. In contrast to Er doped Si, which shows hardly any PL, the Er^{3+} PL intensity from Er: Porous Si is very strong at room temperature and is only weakly affected by the deleterious process known as temperature quenching (see Figure 32 and 33). More detailed studies on the spectroscopy of Er: Porous Si were conducted and have provided valuable insight in the Er^{3+} excitation and de-excitation mechanisms. Optimization of the luminescence properties of Er doped Porous Si is currently in progress and electroluminescence studies will be carried out in the near future.

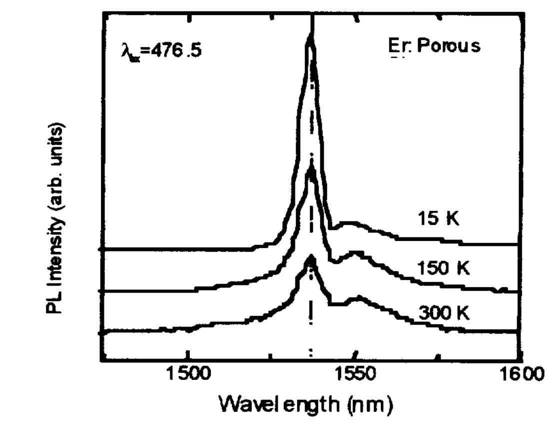

Figure 32. Photoluminescence spectra of Er doped porous Si at different temperature. The Er luminescence was found to be very strong at room-temperature.

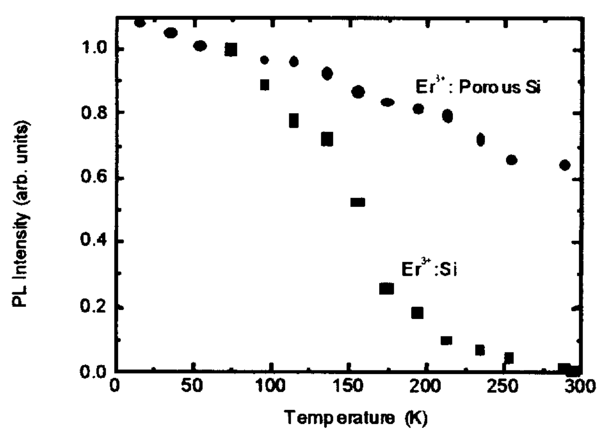

Figure 33. Comparison of the temperature dependence of the 1.54 μm Er PL integrated intensity between Er: Porous Si and Er: Si. In contrast to Er: Si, Er: Porous Si emits strongly even at room temperature.

The second class of Er hosts materials we started to investigate are III-nitride semiconductors including GaN, AlN, and $Al_{1-x}Ga_xN$. III-nitride semiconductors are of enormous current interest for use as blue lasers, UV detectors, as well as for potential high temperature electronic devices. These materials have a band-gap ranging from 3-6 eV and are characterized by a high thermal conductivity, mechanical stability, and chemical inertness. In collaboration with the University of Florida, Hughes Research Laboratories, and the Army Research Office, we initiated the first systematic study to develop a rare earth doped III-nitride electroluminescence device. The III-nitrides are grown at the University of Florida. Rare earth doping is carried out either during growth or through ion implantation at Hughes Research Laboratories. First Er: AlN and Er: GaN films have been successfully prepared at the University of Florida and initial optical measurements have indicated a high 1.54 μm Er^{3+} luminescence efficiency. Figure 34 shows the photoluminescence spectrum of Er: GaN. We found that the integrated luminescence intensity is almost temperature independent. The high luminescence efficiency of Er: GaN indicates the potential of this material for device applications. Attempts to manufacture an Er: GaN electroluminescence diode are currently underway.

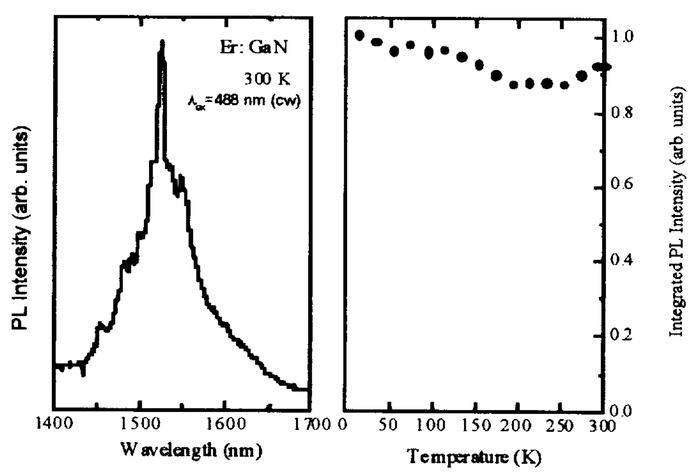

Figure 34. Photoluminescence spectrum of Er: GaN at room temperature. The luminescence efficiency of Er: GaN is more than 90%.

In order to gain deeper insight in the Er^{3+} excitation mechanisms of Er doped III-nitride semiconductors, we carried out initial photoluminescence excitation (PLE) measurements. A typical PLE spectrum is shown in Figure 35 for Er: GaN and Er: AlN. The PLE results indicated that Er^{3+} ions can be excited through either direct optical intra-4f transitions (sharp line at 525 nm) or indirect carrier mediated processes involving defects in the semiconductor host (underlying broad band). More detailed studies on the Er^{3+} PL excitation mechanism and efficiency as a function of material preparation are in progress. Understanding the microscopic physical processes of the Er^{3+} luminescence excitation will play a key role in the advancement of this new class of materials for practical device applications. More work on the luminescence of Er doped III-nitride semiconductors is in progress.

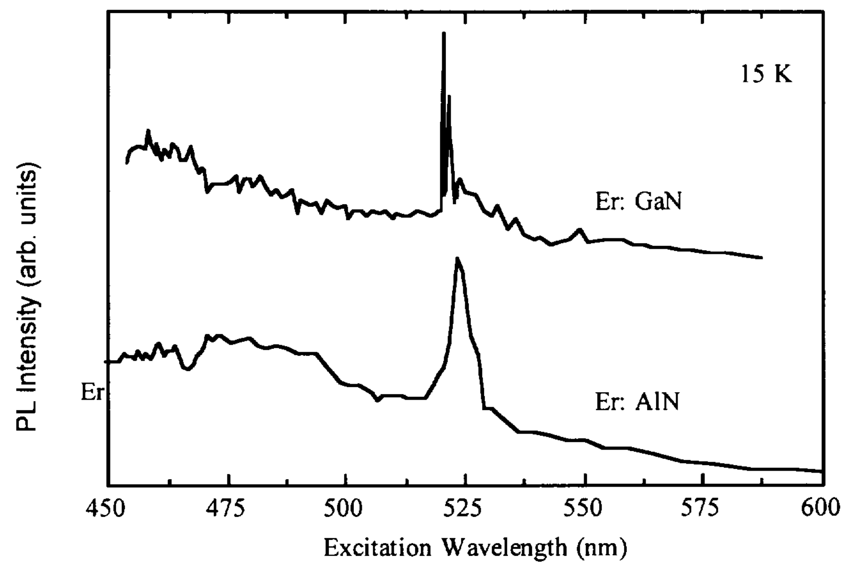

Figure 35. Photoluminescence excitation spectrum of Er doped GaN and AlN.

3.4.4 References

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3.5 Laser Development and Lidar Applications

Investigator: Dr. Thomas Chyba

Visiting Assistant Research Professor:
Dr. Thomas Zenker

Postdoctoral Fellow
Dr. Chuan He

Graduate Students
Mr. Romuald David
Mr. Sangwoo Lee
Mr. Christophe McCray
Mr. Stephen Sylvan

Undergraduate Students
Ms. Desireé Batth
Ms. Cheskeesha Clingman
Mr. Michael Lucas

3.5.1 Research Objectives

The research objectives of the laser development and lidar applications research group within RCOP are:

1) Development of lasers for lidar remote sensing of the atmosphere,
2) Development of complete lidar systems
3) Modelling of lidar systems
4) Field measurements with lidar systems,
5) Interpretation of satellite and lidar data using NASA-LaRC's photochemical/transport model in order to understand atmospheric chemistry and physics,
6) Experimental and theoretical research in laser physics, and
7) Development of laser diagnostic techniques for research or industrial applications.

3.5.2 Synopsis of Research Accomplishments

1) Generation of UV wavelengths suitable for ozone lidar measurements in a novel, all-solid state system.
2) Experimental and theoretical research in laser processes involving Stimulated Raman Scattering in barium nitrate crystals.
3) Development and characterization of an OPO-based laser transmitter suitable for lidar measurements of trace gases such as methane in the 1.5 to 4.0 micron region.
4) Development of an optical receiver for infrared lidar measurements.
5) Laser development and field measurements with an airborne water vapor lidar system through a cooperative agreement with NASA Langley.
6) Development of tropospheric chemistry simulation through a cooperative agreement with NASA Langley for interpretation of field data using global photochemistry/transport simulations.
7) Development of an elastic-backscattering lidar model to compare with measurements made with NASA Langley aerosol lidar systems.
8) Development of high power visible and UV laser sources for photon-electron backscattering experiments at Thomas Jefferson National Accelerator Facility (TJNAF).

3.5.3 Synopsis of activities leading to greater involvement in the NASA-related research community

1) To address the Mission to Planet Earth science priority to understand atmospheric ozone, we are developing advanced lidar technology based upon our solid state Raman laser. Our Partnership Proposal to build a complete compact ozone lidar system based on this technology was approved by NASA.
2) To address the MTPE science priority to understand climate variability, we are constructing a wavelength-stabilized differential absorption lidar system to measure greenhouse gases in the 1.5 to 4.0 micron region.
3) In a direct application of MTPE technology to improve commercial aircraft safety, aerosol lidar systems at NASA Langley are being utilized to study the wake vortices produced by aircraft. We are supporting this effort through assisting with measurements and through theoretical studies whose goal is to improve the accuracy of these measurements.
4) Through a cooperative agreement with NASA Langley, we are collaborating on the development of an airborne water vapor lidar system. This directly addresses the MTPE priority to understand the role of water vapor in atmospheric processes.
5) Through a cooperative agreement with NASA Langley, we are utilizing global tropospheric trace gas data sets and developing tropospheric photochemical simulation codes to address the MTPE priority to understand the anthropogenic influence on the earth's lower atmosphere. A proposal to extend this originally two year cooperative agreement through a third year has been approved by NASA Langley.
6) Dr. Chyba co-taught a new graduate course, Physics 726, Special Topics in Optical Remote Sensing, with Dr. Jack Fishman of the Chemistry and Dynamics Branch, Atmospheric Science Division, at NASA Langley. In addition, for this course, Dr. James Russell (formerly at NASA Langley) in the Hampton University Atmospheric Science Program presented a lecture on passive remote sensor techniques utilized in NASA atmospheric satellites. During this semester, Dr. Edwin Eloranta of the University of Wisconsin presented a seminar on high spectral resolution lidar, and Dr. Michael Hardesty of the NOAA presented a seminar on wind measurements with coherent lidar. The training of graduate students in this NASA-related research area promotes their future involvement in NASA's mission.

Program Management

Resources

The University has agreed to allow the refurbishment of the observatory for dual use for astronomy and as a lidar ground test station.

New University Partnerships

Drs. Chyba and Hommerich of RCOP are participants in a proposed $10,000,000 NSF Engineering Research Center, the Center for Atmospheric Monitoring and Sensor Engineering, proposed by Hampton University in partnership with the University of Illinois. The preproposal has been approved by NSF, and the final proposal is being drafted.

Dr .Chyba and other Hampton University faculty and students and Thomas Jefferson National Accelerator Facility staff are collaborating with faculty and students from the University of Virginia and Oregon State University to develop high power visible and uv laser sources for Compton Backscattering Experiments at TJNAF.

Dr. Chyba has a cooperative agreement with NASA Langley to jointly develop an airborne water vapor lidar system.

Dr. Zenker has a cooperative agreement with NASA Langley, to utilize a global tropospheric trace gas data sets and develop a tropospheric photochemical simulation code to understand the anthropogenic influence on the earth's lower atmosphere.

Dr. Chyba and Dr. Zenker are collaborating with Kaman Sciences in Albuquerque, NM on the design of a compact ozone lidar system through their NASA Partnership Award.

Dr. Chyba is collaborating with Dr. Karl Koch from USAF Phillips Laboratory on an experiment to test the predictions of a theoretical model of nonlinear frequency conversion developed by Dr. Koch and coworkers.

Measures Taken to Disseminate Results

Dr. Chyba has had numerous informal technical discussions at NASA Langley and has made several presentations there concerning the results of his research.

Dr. Chyba has presented the results of his research at the University of New Mexico, at Kirtland Air Force Base, and at the Thomas Jefferson National Accelerator Facility. He has had technical discussions with staff from the National Institute of Standards and Technology, faculty from the Universities of Illinois, Utah, and Wisconsin, and staff from the National Oceans and Atmospheric Administration.

Dr. Chyba, his postdoctoral fellow, and his students have presented papers at the Optical Society of America's Topical Meeting on Atmospheric Remote Sensing, the Optical Society of America's Annual Meeting, the Conference on Electro-Optics and Lasers, the International Laser Radar Conference, the Meeting of the American Physical Society, and the NASA-URC-TC Conference. They have published in the refereed literature:

3.5.4 Technical Accomplishments and Plans
Briefs on the progress of each research project

3.5.4.1 Demonstration of a compact, all-solid state ozone DIAL system.

(Mr. Christophe McCray, Dr. Chuan He, Dr. Thomas Zenker)

The objective of this project is to develop a compact, all-solid state laser source, suitable for ozone DIAL measurements. Our approach is to utilize a Nd:YAG laser and nonlinear conversion techniques to generate the wavelengths. A complete lidar system including data acquisition electronics is being funded by a NASA Partnership Award. In partnership with engineers at Kaman Sciences, we are developing a compact lidar receiver as part of this effort.

The Raman shifting technique has been used extensively to widen the spectral coverage for various laser applications. Although the first $Ba(NO_3)_2$ Raman laser in the visible region was reported in 1986, most of the recent research on this material has focussed on creating eye-safe IR sources. A $Ba(NO_3)_2$ Raman laser pumped at 532 nm by a frequency-doubled Nd:YAG laser can generate first Stokes laser output at 563 and second Stokes at 599nm, in addition to other Stokes wavelengths. Using a frequency doubling or sum-frequency generation technique, UV output at 282 nm and 299 nm can be obtained, providing on-line and off-line pulse pairs for an ozone DIAL system. One candidate system is illustrated in figure 1. This all solid-state system is very compact and has great potential to be efficient and reliable. These attributes are very important for airborne and spaceborne lidar.

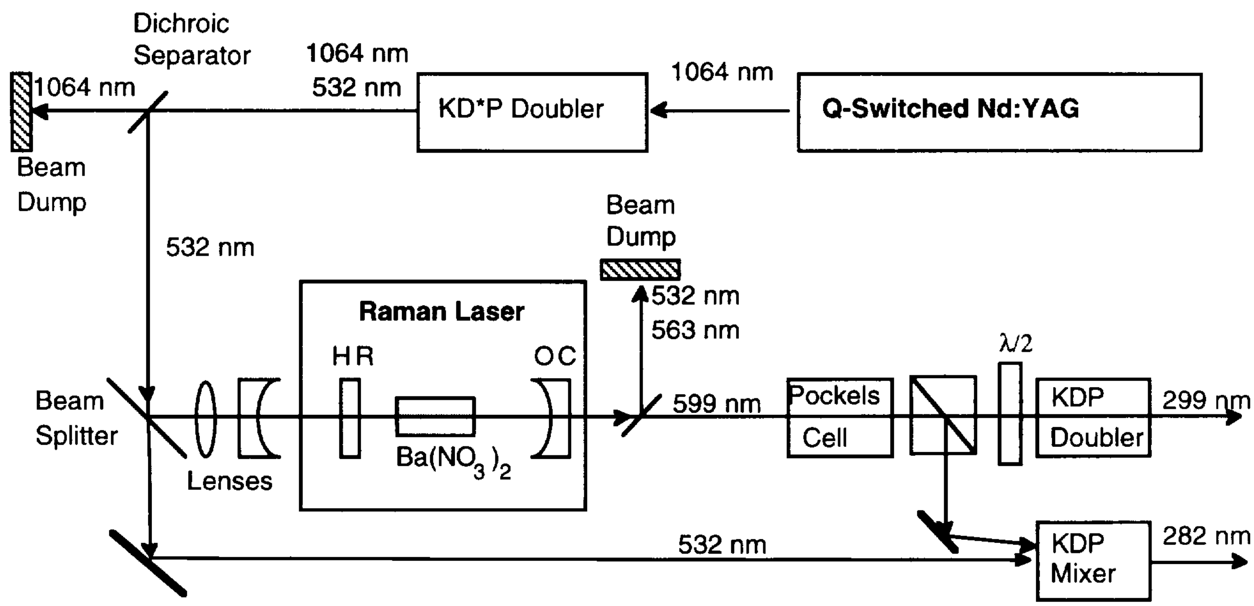

Figure 36. The all-solid state UV laser source

We started our investigations with the simple end-pumped laser cavity shown in figure 1. A flat high reflector (HR) and an output coupler (OC) form a stable resonator. The barium nitrate crystal is mounted in a sealed housing filled with index matching fluid. The pockels cell-polarizing beam splitter in the diagram serves as a switch so that every other laser pulse is either the on-line or the off-line wavelength.

We achieved very high (40%-50%) conversion into the orange (599 nm) and the yellow (563 nm) from the green (532 nm). Due to high beam divergence, both the mixing and doubling efficiencies are very low. At present, we are modeling the nonlinear processes in order to redesign the oscillator to optimize the UV conversion. We have measured the line broadening due to the Raman process and found it to be insignificant. We are also testing an oscillator-amplifier design. The major advantage of this last approach is that a low power oscillator can be used to generate a low divergence beam which can be amplified with a second barium nitrate crystal to achieve high energies.

3.5.4.2 Utilization of tunable narrowband OPO laser technology for differential absorption lidar measurements in the 1.5 to 4.0 micron region.

(Mr. Sangwoo Lee, Dr. Thomas Zenker)__

A differential absorption lidar system based upon a narrow-band tunable OPO laser is under development for measurements of atmospheric gases in the 1.5 to 4.0 micron spectral region. These gases are of interest to a variety of government agencies and industries. The system configured for measurements of atmospheric methane is illustrated in Figure 37. The OPO laser produces tunable pulses in the 3.2 micron region with which the absorption of atmospheric methane or other molecules can be measured. The OPO also produces simultaneous pulses at 1.57 microns which can be used to measure atmospheric aerosols. The diagnostic White cell is used to verify that the laser wavelength is maintained on the peak of the absorption feature of choice. The lidar receiver has two channels, one for the 3.2 micron region and one for the 1.5 micron region.

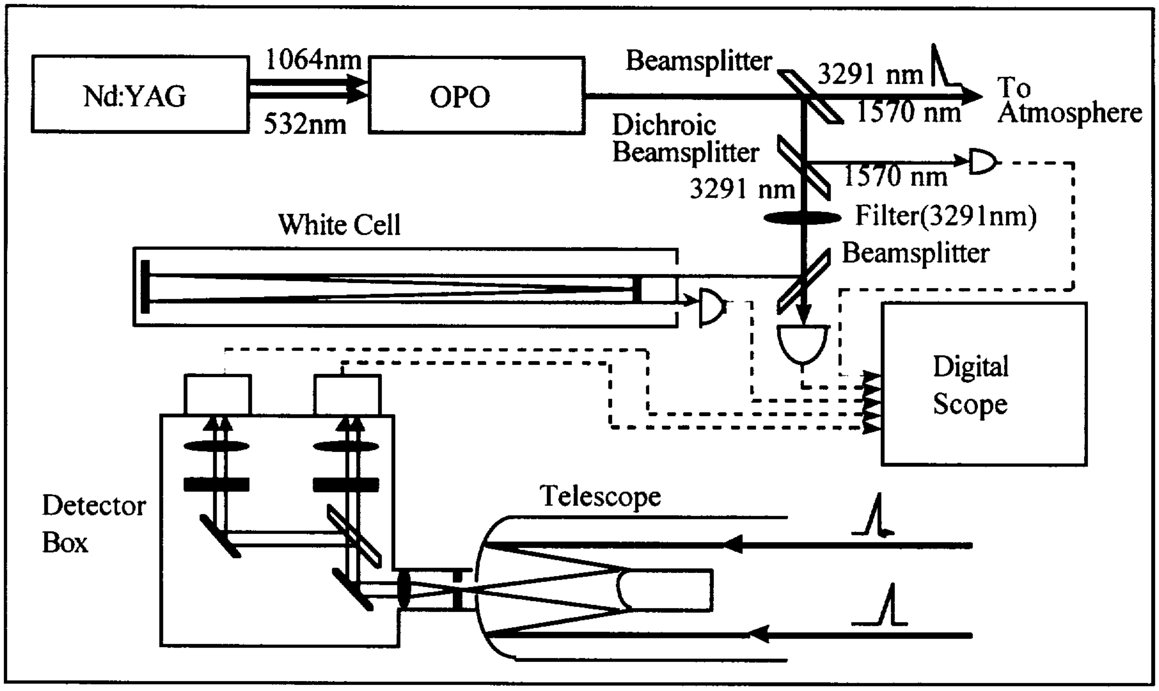

Figure 37. The tunable, narrowband, near-IR lidar sytem.

Initial measurements have been performed using the absorption cell in the laboratory in order to identify possible spectral lines for future measurements and to evaluate the laser as a source for differential absorption lidar. A water vapor line was used to verify the high (>99.9%) spectral purity of the laser source. Preliminary calculations show that range-resolved measurements of methane concentrations are possible to several hundred meters with present pulse energies. Hard-target (total column content) measurements are possible to several kilometers. An additional OPA stage to increase the output energy is under examination. Lidar measurements of local sources such as the university power plant plume will be made.

3.5.4.3 Development of lasers and lidar system technology for airborne water vapor measurements

(cooperative agreement with NASA Langley supporting Dr. Chyba).

Detailed knowledge of the distribution of water vapor in the troposphere is important because of its role in affecting global climate. It is the most important greenhouse gas, accounting for 73% of the Earth's grey body optical depth. Water vapor is very important in global radiative balance and leads to the formation of clouds which play a crucial role in global climate. At present, water vapor distributions in the upper troposphere are not well characterized due to current limitations of radiosondes and satellites.

A goal of the Atmospheric Sciences Division of the NASA Langley Research Center is to improve its capability to make accurate remote measurements of atmospheric water vapor. The present differential absorption lidar (DIAL) system utilized by the Lidar Applications Group at NASA Langley is capable of making such measurements in the middle and lower troposphere. This lidar utilizes dual alexandrite lasers operating in the 720-nm wavelength region. In this project, laser research has been performed with the goal of improving the range and accuracy of this system through theoretical and experimental studies.

The present NASA LaRC water vapor DIAL system participated in the LASE Validation Experiment during the fall of 1995. This field experiment pinpointed several limitations which this present research is addressing: (1) limited spectral purity of the ring laser, (2) limited wavelength accessibility of the laser diode seed source, (3) mechanical and optical complexity due to the cooled diode lasers, (4) limited output energy, and (5) ring laser alignment sensitivity.

To address these limitations, spectral purity measurements were performed using a custom external cavity laser diode as a seed source for the on-line ring laser. The measured spectral purity was equal to that of the cooled laser diode seed source. The advantages of this device are: (1) continuous tunability, (2) no need for low temperature cooling and the associated high vacuum environment, and (3) ease of alignment and maintenance. Secondly, the ring laser has been redesigned to improve its efficiency, and insensitivity to misalignment, output energy, and spectral purity. This design incorporates new electronics to trigger the ring laser when it is resonant with the seed source, thus maintaining single longitudinal mode operation and high spectral purity for each laser pulse. This system is currently being laboratory tested.

3.5.4.4 Synergistic utilization of lidar and satellite data sets to test and refine state-of-the-art NASA Langley atmospheric models

(cooperative agreement with NASA Langley supporting Dr. Thomas Zenker).

A goal of the Atmospheric Sciences Division of the NASA Langley Research Center is to develop the capability to accurately analyze atmospheric data obtained from lidar and satellite measurements utilizing numerical models of the physics and chemistry of the atmosphere. The objective of this project is to combine recent advances in atmospheric modeling with recently obtained lidar and satellite measurements in order to understand how emissions from anthropogenic sources have perturbed the composition of the atmosphere.

The high vertical resolution and relatively large spatial extent of lidar data, when combined with satellite measurements, provide a uniquely valuable data set. Comparison with model calculations will enable further strides in the accuracy of these models, including the incorporation of improved photochemical mechanisms. The data sets, computer facilities, and the presence of a world-class general circulation model at NASA Langley provide unique resources for this effort. Cooperation with scientists at NASA currently developing related atmospheric models facilitates rapid advances in this research. The results of this effort will enhance the capability of NASA scientists to understand and predict atmospheric processes and provide guidance for future instrument development, future field measurements, and data analysis techniques.

The existing stratospheric chemistry module has been modified to also simulate the basic tropospheric chemistry. The mechanisms to incorporate trace gas source, e.g. for NO_x, and dry deposition sinks for H_2O_2, CH_3OOH, O_3, HCHO, HNO_3, and NO_2, are incorporated. Currently, the processing of the satellite tropospheric ozone residual (TOR) is being reevaluated in order to improve and quantify the accuracy of the TOR data product which will be compared to model simulation results.

3.5.4.5 Theoretical modelling and experimental tests of an aerosol lidar system for wake vortex measurements at NASA Langley

(Mr. Steven Sylvan; cooperative research with Dr. L. Poole and Dr. C. Hostetler, Aerosol Research Branch, NASA).

Since 1993, the Aerosol Research Branch at NASA Langley has been conducting a series of multiwavelength lidar measurements of aircraft exhaust plumes in the wake vortex regime. These measurements are in support of the Subsonic Assessment of NASA's Atmospheric Effects of Aviation Program, which seeks to determine the effects of commercial subsonic aircraft upon the atmosphere.

The objective of the present research project is to develop a computer model of the lidar returns from the exhaust plumes in order to (1) understand present measurements and (2) predict optimal lidar parameters for future measurements. This model incorporates measured particle size distributions from in-situ measurements, laser wavelength, energy, repetition rate, and divergence information; receiver optical bandwidth, throughput, laser beam overlap and field of view information; detector and amplifier noise characteristics; and atmospheric scattering, extinction, and solar background information.

3.5.4.6 Development of high-Q resonant optical cavities for Compton scattering at TJNAF (formerly CEBAF)

(Mr. Romuald David; collaboration with C. Keppel (HU), R. Ent (HU), B. Norum (UVA), T. P. Welch (OSU), D. Gaskell (OSU), C. Sinclair (TJNAF), M. Poelker, (TJNAF)).

The use of Compton scattering of photons from high energy electrons in order to produce high energy, polarized photons was first suggested in 1962. Since then it has been employed at a number of laboratories. There are three major uses of the Compton scattered photons at TJNAF: (1) continuous monitoring of the electron beam energy, (2) continuous monitoring of the electron beam polarization, and (3) a continuous source of polarized 1.8 GeV photons for physics experiments. Each application requires a different optimal incident photon wavelength. For initial prototype experiments, 514.5 nm photons produced by an Argon-ion laser will be used, along with frequency-doubled photons at 257 nm. Both of these wavelengths are suitable for beam polarization measurements. The 257 nm photons are also suitable for the high energy polarized photon source.

In order to produce a high photon flux in the visible, the Argon-ion laser is locked to an optical build-up cavity. Intracavity power inside such ring resonators have been demonstrated to reach 1000 to 50,000 times the incident optical power. The Argon-Ion laser photons can also be frequency doubled in an external cavity to produce a beam of uv photons. These photons can then be used to generate high uv intracavity power in an external ring resonator. When housed in a vacuum chamber centered on the beam line, photons in the ring resonator can be made to Compton scatter from the TJNAF electron beam.

At present, build-up cavities and doubling cavities are being tested at TJNAF with the initial objective to demonstrate and measure high intracavity visible and uv powers. Subsequent to this table-top laboratory demonstration, funding will be sought to enclose the resonator in a vacuum housing and insert it into the beam line.

4. URC PUBLICATION CITATIONS

4.1 Refereed Journals and Proceedings

1996

Dr. Chyba

1. He, C. and T. H. Chyba, "Solid State Barium Nitrate Raman Laser in the Visible Region," Conference on Lasers and Electro-Optics (CLEO), Paper CPD-15, Anaheim, CA, 1996.
2. Chyba, T. H., P. Ponsardin, N. S. Higdon, R. J. De Young, C. F. Butler, and E. V. Browell, "Advanced Airborne Water Vapor DIAL Development and Measurements", 18th International Laser Radar Conference, Berlin, July 22-24, 1996, paper E22.
3. Chyba, T. H., C. L. McCray and C. He, "All solid-state uv laser sources based on barium nitrate raman scattering for ozone DIAL system", Optical Society of America 1996 Annual Meeting, Rochester, New York, October 21, 1996, paper MYY3.
4. McCray, Christophe, and T. H. Chyba, "Thermal lensing measurements in barium nitrate", Optical Society of America 1996 Annual Meeting, Rochester, New York, October 21, 1996, paper MYY4.
5. R. Poole, J. M. Alvarez, C. A. Hostetler, R. J. DeCoursey, G. S. Kent, G. Hanson, and S. S. Sylvan, "Ground based lidar observations of Boeing 737 exhaust particulates in the near field regime", presented at the Spring AGU meeting, Baltimore, Md., 1996

Dr. Hömmerich

6. X. Wu, U. Hömmerich, K. Grasza, S. B. Trivedi, and Zengchen Yu, "Optical properties of Cr^{2+} ions in $Cd_{0.85}Mn_{0.15}Te$", accepted for presentation at the International Conference on Luminescence, Prague, August 1996.
7. X. Wu, U. Hömmerich, J. D. Mackenzie, C. R. Abernathy, S. J. Pearton, R. N. Schwartz, R. G. Wilson, and J. M. Zavada, "Photoluminescence study of Er: AlN", accepted for presentation at the International Conference on Luminescence, Prague, August 1996.
8. R. White, X. Wu, U. Hömmerich, F. Namavar, and A. Cremins-Costa, "Characterization of the visible and infrared (1.54 μm) luminescence from Er-doped porous Si", presented at the Material Research Society 1996 Spring Meeting, San Francisco, CA.
9. V. R. Davis, X. Wu, U. Hömmerich, K. Grasza, S. B. Trivedi, and Zengchen Yu, "Evaluation of Cr^{2+} doped $Cd_{0.85}Mn_{0.15}Te$ as a mid-infrared tunable solid-state laser material", Abstract submitted to the Annual Meeting of the Optical Society of America, 1996.
10. R. White, X. Wu, U. Hömmerich, F. Namavar, and A. Cremins-Costa, "Excitation mechanism of Er doped Porous Si", submitted to the 12th Interdisciplinary Laser Science Conference 1996.
11. U. Hömmerich, F. Namavar, A. Cremins, and K. L. Bray, "A spectroscopic study on the luminescence of Er in porous Si", Appl. Phys. Lett. 68, 1951, 1996.
12. R. White, X. Wu, U. Hömmerich, F. Namavar, and A. Cremins-Costa, "Characterization of the visible and infrared (1.54 μm) luminescence from Er-doped porous Si", Material Research Society Symp. Proc., Vol. 422, 1996.
13. M. Zavada, R. G. Wilson, R. N. Schwartz, J. D. Mackenzie, C. R. Abernathy, S. J. Pearton, X. Wu, and U. Hömmerich, "Characterization of Er-Doped III-V nitride epilayers prepared by MOMBE, Material Research Society Symp. Proc., Vol. 422, 1996, in press.
14. U. Hömmerich, F. Namavar, A. Cremins, and K. L. Bray, "A spectroscopic study on the luminescence of Er in porous Si", Appl. Phys. Lett. 68, 1951, 1996.
15. U. Hömmerich, X. Wu, F. Namavar, A. Cremins, and K. L. Bray, "Photoluminescence properties of Er doped porous silicon", Mat. Res. Soc. Symp. Proc., 405, 1996, 215-220.
16. U. Hömmerich, F. Namavar, A. M. Cremins, and K. L. Bray, "Photoluminescence Properties of Er-Doped Porous Silicon", presented at the 1995 Fall Meeting of the Materials Research Society.
17. V. Davis, U. Hömmerich, and G. B. Loutts, "Near infrared luminescence properties of Mn^{5+}: FAP, First National NASA-URC Student Conference, Greensboro, North Carolina 1996.

18. R. White, X. Wu, U. Hömmerich, F. Namavar, and A. Cremins-Costa, "Characterization of visible and infrared luminescence from Er-doped porous silicon, presented at the 1996 Spring Meeting of the Materials Research Society.
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Dr. Mathur and Dr. Lowe

20. Electrical Properties of CuO Doped Sodium Borate Glasses: S.C.Mathur, Y.K.Sharma, B.K.Sharma, D.C.Dube, and A.S.Bhalla; Phys. Stat. Sol. (a) 153, 57-63 (1996).
21. Calvin W. Lowe, and S.C.Mathur; PERIODIC DIELECTRIC STRUCTURES: Theme lecture delivered at IX National Seminar on Ferroelectrics and Dielectrics held at National Physical Laboratory, New Delhi, India, from October 8 - 11, 1996.
22. Calvin W. Lowe, and S.C.Mathur, PHOTONIC BANDGAP CRYSTALS: INVITED TALK delivered at 3rd Intensive tutorial and International conference on semiconductor materials and devices held at Delhi University and National Physical Laboratory, New Delhi, India from December 16 -21, 1996 .
23. Kang I. Seo, Satish C. Mathur, and Calvin W. Lowe,Growth Mechanism and Optical Properties of a New Nitroaromatic Compound, 17th congress of the International Commission for Optics (Taejon, Korea), Aug. 19-23, 1996.
24. Kang I. Seo and Calvin W. Lowe,Optical Waveguide Based on Organic Mixed MNA-MAP Evaporated Thin Films, Polymeric and Organic Materials for Optical Applications (Orlando, FL), Aug 25-30, 1996.

Dr. Lyons

25. Lyons, "Image Repoduction of Bragg Gratings", Proceedings of IOC 17. Optics for Science and Technology, Aug. 1996.

Dr. Tabibi

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27. Bagher M. Tabibi, et. al.," Non-Intrusive Optical Diagnostic Methods for Flowfield Characterization", Proceeding of the NASA URC Technical Conference, Vol. 1, pp. 711-716, 1997.
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29. Charles A. Terrell, Bagher M. Tabibi, and Ja H. Lee, "Electron Beam Fluorescence of N_2^{+*} Quenching Rate", Bulletin of the APS, Program of the 1996 Fall Meeting of the SESAP Society, Vol. 41, No. 8, November 1996. Abstract AC 2
30. Darrell A. Spraggins, Bagher M. Tabibi, Ja H. Lee, and Leonard M. Weinstein, "A Small-Field, High-Sensitivity Focusing Schlieren System for Flowfield Visualization", Bulletin of the APS, Program of the 1996 Fall Meeting of the SESAP Society, Vol. 41, No. 8, November 1996. Abstract AC 9.
31. Dung X. Nguyen, Cecily J. Smith, Bagher M, Tabibi, and Ja H. Lee, "Preliminary Operation of a Solar Thermal-Electric Propulsion (STEP) System", Bulletin of the APS, Program of the 1996 Fall Meeting of the SESAP Society, Vol. 41, No, 8, November 1996. Abstract AB 5.
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Dr. Temple

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35. C.J. Pittman and D. A. Temple, "Outreach Programs in Physics at Hampton University," Proceedings of the SPIE 1996 Symposium on Optical Science, Engineering and Instrumentation, Talk 2809-30, Denver, Colorado, August 4-9 (1996)
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Dr. Zenker

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2. F. Etop, K. I. Seo and C. T. Lee, Binomial Mixed State Reflected from a Grey Well, Quantum Semiclass. Opt. 7, 1-7, 1995.
3. G. Harvey, T. H. Chyba, and M. Cimolino,"Cleanliness and damage measurements of optics in atmospheric sensing high energy lasers" Proceedings of the Annual Symposium on Optical Materials for High Power Lasers, PROC SPIE 2714, 696 - 706, 1995.
4. G. Harvey, T. H. Chyba, and M. Cimolino,"Cleanliness and damage measurements of optics in atmospheric sensing high energy lasers" presented at the Annual Symposium on Optical Materials for High Power Lasers, Boulder, Colorado, October 30, 1995.
5. Kang I. Seo, Growth Mechanism for Aromatic Organic thin Films, 14th Annual Meeting Alabama Images and Microscopy (Birmingham, AL), March 23-24, 1995.

6. U. Hömmerich, X. Wu, F. Namavar, A. Cremins, and K. L. Bray, "Photoluminescence properties of Er doped porous silicon", presented at the Material Research Society 1995 Fall Meeting, Boston, MA.
7. Kang I. Seo, Isaac Jones, and Calvin W. Lowe, Growth and Characterization of Vacuum Deposited Organic Thin Films, Organic thin Films for Photonic Applications (Portland, OR) ACS 1995 Tech. Digest Series 21 p85, Sept. 11-14, 1995.
8. Q. N. Wang and D. A. Temple, "Photorefractive Transport in Transverse Geometry Thin Films," Talk MH1, International Conference on Lasers 95, Charlston, SC, Dec. 4 - 8, 1995
9. T. M. Thaik, Y.S. Choi, C.A. Terrell, B.M. Tabibi, and J.H. Lee, "Thermal-Electric Propulsion with Magnetoplasmadynamic Acceleration", Presented at 62nd Annual Meeting of SESAPS, Tallahassee, Fl, Nov.1995, Bulletin of the APS, Vol. 40, No.13, DC 7.
10. D. Nguyen, M. Thaik, Y.S. Choi, C.A. Terrell, B.M. Tabibi, and J.H. Lee, "Thermal-Electric Propulsion with Magnetoplasmadynamic Acceleration", Presented at 62nd Annual Meeting of SESAPS, Tallahassee, Fl, Nov.1995, Bulletin of the APS, Vol. 40, No.13, DC 7.
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2. Bagher M. Tabibi, Sang H. Choi, and Ja. H. Lee, "Thermal-Electric Propulsion with magnetoplasmadynamic Acceleration", 25th AIAA Plasmadynamics and Lasers Conference, June 20-22, 1994/Colorado Springs, Co., Paper AIAA 94-2468.
3. Charles A. Terrell, Dr. Bagher M. Tabibi, et al, "Effect of Argon on N2+ First Negative Emission and Modal Temperatures", Presented at 61st Annual Meeting of SESAPS (Nov., 1994).
4. I.H. Hwang, "Second Harmonic Generation of Diode Pumped Nd:YAG with KTP Crystal," 72nd Annual Meeting of the Virginia Academy of Science, James Madison University, Harrisburg, VA May 19-20, 1994

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1. Charles A. Terrell, Dr. Bagher M. Tabibi, et al, "CW Iodine Laser Performance of t-C4F9I Under Closely-Simulated AM0 Solar-Pumping", Poster presented at CLEO,1993 (May, 1993).
2. Charles A. Terrell, Dr. Bagher M. Tabibi, et al, "CW Iodine Laser Performance of t-C4F9I Under Closely-Simulated AM0 Solar Pumping", Honorable Mention Presentation at the 71st Annual Meeting of the Virginia Academy of Science (May, 1993).
3. Farrukh and N. Barnes, "Time-dependent temperature profiles in end-pumped laser rods: non circular pump cross section", TuU7, Optical Society of America's Annual Meeting, October 3-8, 1993.
4. Usamah Farrukh and Norman Barnes, "Time-dependent temperature in laser block crystals: impact of selective cooling", TuU8, Optical Society of America's Annual Meeting, October 3-8, 1993.
5. Zhou, A. K. Hodari, I. H. Hwang and D. D. Venable, "An end-pumped Cr:Nd:GSGG laser," Virginia Journal of Science 44, 109 (May 1993).
6. Usamah Farrukh and Philip Brockman, "Temperature Distribution in end-pumped Crystal Laser Rods: Transient and Spatial Variation," Applied Optics, Vol 32, No. 12, pp. 2075-2082 (1993).
7. Charles A. Terrell, Dr. Bagher M. Tabibi, et al, "CW Iodine Laser Performance of t-C4F9I Under Closely-Simulated AM0 Solar-Pumping", Conference on Lasers and Electro-Optics CLEO,1993.

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1. B. Tabibi, J. H. Heinbockel, R. C. Costent, and J. H. Lee,"A 30-W CW Solar Simulator-Pumped Iodine Laser", CLEO'92 Conference, Anaheim, CA., 1992, Paper CWG8.

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4. C. Terrell, B. M. Tabibi, et al, "CW Iodine Laser Performance of t-C4F9I Under Closely-Simulated AM0 Solar Pumping", Presented at 59th Annual Meeting of SESAPS (Nov. 1992).

4.2 Other Publications and Presentations

1. McCray, Christophe, and T. H. Chyba, "Barium nitrate Raman laser development for the remote sensing of ozone", NASA University Research Center Technical Conference, 1997, Albuquerque, New Mexico, February 18, 1997, paper TUP5-03.
2. C. L. McCray, and T. H. Chyba, "Barium nitrate raman laser development for the remote sensing of ozone", in NASA University Research Centers Technical Advances on Education, Aeronautics, Space, Autonomy, Earth, and Environment, Vol. 1, Proceedings of the NASA URC Technical Conference 1997, ACE Center Press, Albuquerque, (1997) pp. 497-500.
3. C.W.Lowe, S.C.Mathur, Renuka Verma, and Kang I. Seo; STUDIES ON PTCDA/NTCDA MULTIPLE QUANTUM WELLS: Presented at NASA URC _ TC '97, held at Albuquerque, New Mexico, USA from February 16-19, 1997.

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1. K. Hodari and D. A. Temple, "Photorefractive properties of Rh Doped Barium Titanate," First National URC Student Conference, Greensboro, North Carolina 1996.
2. R. Samuel, D. Lyons, H. R. Lee, "Strain-Optic Effect for UV-Induced Bragg Gratings", NASA-URC Conference, North Carolina A&T , 1996.
3. U. Spurlock, C. W. Lowe, S. C. Mathur, "Hyperthermal Ion Scattering From Organic Thin Films," NASA URC National Student Conference ,1996.
4. R. Davis, U. Hömmerich and G. B. Loutts, "Near infrared luminescence properties of Mn5+: FAP, NASA-URC Conference, North Carolina A&T, 1996.
5. H. Chyba and R. David,"Progress Report on the Resonant Optical Cavity Development for Compton Scattering at CEBAF," presented at CEBAF, April 11, 1996.
6. H. Chyba, P. Ponsardin, N. S. Higdon, R. J. DeYoung, C. F. Butler, and E. V. Browell, "Airborne Water Vapor DIAL System and Measurements", presented at the LASE Science Meeting, July 2-3, NASA Langley Research Center, Hampton, Va, 1996

1995

1. Robert C. Costen, John H. Heinbockel, Gilda A. Miner, Willard E. Meador, Jr., Bagher M. Tabibi, Ja H. Lee, and Michael D. Williams, "Reduced Dimer Production in Solar-Simulator-Pumped Continuous Wave Iodine Laser Based on Model Simulations and Scaling and Pumping Studies", NASA, Technical paper 3486, March 1995.
2. M. Tabibi, Y. S. Choi, D. X. Nguyen, S. H. Choi, and J. H. Lee,"Thermal-Electric Propulsion with Magnetoplasmadynamic Acceleration", abstract submitted to AFOSR Contractor's Meeting in Space Power and Propulsion. May 17-19, 1995, Chicago, Illinois.
3. Robert C. Costen, John H. Heinbockel, Gilda A. Miner, Willard E. Meador, Jr.,Bagher M. Tabibi, Ja H. Lee, and Michael D. Williams, "Reduced Dimer Production in Solar-Simulator-Pumped Continuous Wave Iodine Laser Based on Model Simulations and Scaling and Pumping Studies", NASA, Technical paper 3486, March 1995.

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1. "Electron-Beam Fluorescence for Flowfield Diagnostics", Bagher M. Tabibi, A presentation to the NASA Technical advisory Committee, RCOP, Department of Physics, Hampton University, October 20, 1994.
2. A. K. Hodari and D. R. Lyons, "Length limited Bragg reflection gratings: fabrication and experimental evaluation," Presented to the 1994 Annual Meeting of the National Society of Black Physicists (Apr 1994).
3. C. A. Terrell, B. M. Tabibi, et al., "Effects of Argon on N2+ First Negative Emission and Modal Temperatures", Poster Presentation at 2nd Annual RCOP Forum (Sept., 1994).
4. D. Lyons, "Bragg Reflection Filter Wavemeter for the Writing of Multiple Transverse Holographic Gratings", Materials Science Conference, Washington, D.C., October 13-15, 1994.
5. D. Lyons, "Interferometric Fiber Optic Sensors with Applications to Smart Structures", The 17th Annual Meeting of the National Society of Black Physicists", XXI Day of Scientific Lectures, Newark, New Jersey, April 20-23, 1994.
6. D. Lyons, "Fiber Optic Sensors Research in the Research Center for Optical Physics (RCOP)", NASA-LaRC Smart Materials and Structures Workshop, May 17, 1994.
7. D. Lyons, "Length-limited Bragg Reflection Filters and Their Applications to Smart Structures", 3rd Annual Dr. Phillip R. Young Memorial Lectures, Grambling State University, April 1994.
8. Bagher M. Tabibi, 'Development of Advanced Thermal & Electric propulsion (TEP) System", Department of Physics, Hampton University, Final Report Submitted to AFOSR, November 25, 1994. Grant # F49620-93-1-0611

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2. G. Simms and A. K. Hodari, "A tri-state optical switch for local area fiber optics networks," Proceedings of the Inaugural Forum for the Research Center for Optical Physics: Optical Society of America 19, 69-74 (Sep 1993).
3. Luther R. Gartrell, Bagher M. Tabibi, William W. Hunter,Jr., Ja. H. Lee, and Mark T. Fletcher," Application of Laser Doppler Velocimetet to Chemical Vapor Laser System", NASA TM-4409, January 1993.

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1. Bagher M. Tabibi, "A 46-W CW Solar-Simulator-Pumped Iodine Laser and Development of Laser Diagnostic Experiment", Interim Report February 1, 1992-July 30, 1992, NASA, RCOP, 1992. Grant # NAGW-1-2929.

4.3 Patents

1. "Instrumented Patch for Repair of Fatigue Damaged or Sensitive Structures", P-1(07891), D. R. Lyons, S. M. Reich.
2. "Method of and Apparatus for Calibrating Precisely Spaced Multiple Transverse Holographic Gratings in Optical Fibers," D. R. Lyons, Zolili Ndlela, 1995.

5. Outreach

The outreach program for RCOP consists of three main components: precollege, undergraduate, and teacher enhancement programs. The overall goal of RCOP's outreach program is to provide students with world-class education and training in optics and related disciplines, with a special emphasis on underrepresented students. The faculty of RCOP participate in every aspect of these outreach efforts.

5.1 Precollege Programs

Student Resource Center

The Student Resource Center provides tutoring as well as reinforcement and enrichment in mathematics and science. This center is conveniently located at the Hampton City Schools Administration Building, allowing access to all students in the Hampton City School System. Ms. Apriel Hodari, graduate student, volunteerd at this center every Tuesday and Thursday.

Science Fairs

Ms. Carlane Pittman and Mr. Anthony Siquade, graduate student, judged the second annual Hampton University Laboratory School Science Fair in which third through fifth grade students participated. This school consists of approximately 90% African-American students.

The third annual Hampton University School Science Fair was held in May 1996 and students and faculty assisted in the coordination and judging of the fair.

SHARP PLUS

Sharp Plus is a program funded by NASA in order to provide outstanding underrepresented students from around the country a rich research environment. This program is a collaboration between NASA-Langley and Hampton University through the Quality Education for Minorities (QEM) program. This program began

SHARP Plus is a program funded by NASA in order to provide outstanding underrepresented students from around the country the opportunity to study in a rich research environment. This program is a collaboration between Hampton University and NASA-Langley through the Quality Education for Minorities (QEM) program. This program began June 20, 1996, and ran through August 15, 1996. We had three SHARP Plus students in last year's program. We have created a research environment that seems to be very productive for high school students. It is a team environment in which the faculty mentor, graduate and undergraduate students along with the high school students are all working together. The participants were Ms. Ronalee Lo, Ms. Kasey Patton, and Ms. Courtney Woods. The students were assigned as follows: Ms. Courtney Woods conducted theoretical research with Dr. Khin Maung, Ms. Ronalee Lo conducted optical physics research with Dr. Lowe and Dr. Mathur and graduate student, Melvin Spurlock and Ms. Kasey Patton conducted optical physics research with Dr. Lyons. The student projects are as follows:

Name	Project Title	Mentor
Ms. Ronalee Lo	The Thin Film Growth of Methyl 2-(2,4 -dinitroanilino) propionate	Dr. Lowe
Ms. Ronalee Lo	The Pyroelectric Effect Observed in Triglycine Sulfate Crystals	Dr. Mathur
Ms. Kasey L. Patton	Strain Measurements in Optical Fibers Using Wavelengths Shifts of Bragg Reflection Holograms	Dr. Lyons

5.2 Undergraduate Program

Post-Baccalaureate Summer Research Program (PSRP)

The Post-Baccalaureate Summer Research Program (PSRP) was an eight-week summer program held in 1993 for undergraduates that have completed their senior year of college. This program was held on the campus of Hampton University with 13 participants from universities abroad. The goals of this program were to provide underrepresented undergraduates with experiences in state-of-the-art computer technology, research methods, improvement of mathematical skills and enhancement of technical writing skills. In order to expose students to a variety of research areas, visiting scientists were invited to give seminars on their expertise.

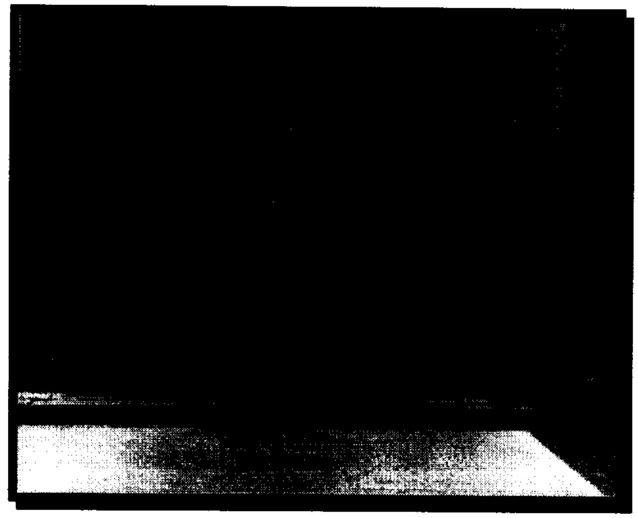

Figure 38. Post-Baccalaureate Summer Research Program participants.

Alliance for Minority Participation - Summer Physics Institute 95 (AMP-SPI)

The Summer Physics Institute (SPI) at Hampton University was scheduled for June 19 through July 28, 1995. The RCOP center offered this institute for junior and senior physics majors. Seven African American female students participated in this program. The academic training consisted of a three-credit hour course on optical and mathematical physics. The students were also paired with research scientists from RCOP and NASA/LaRC.

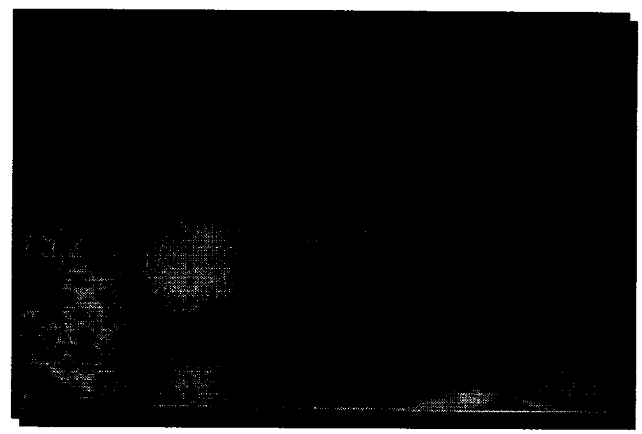

Figure 39. AMP-SPI participant Tyhesha Goss explaining her work to other students.

Undergraduate Institute in Physics 1996 (UnIPhy)

The **Und**ergraduate **I**nstitute in **Phy**sics (UnIPhy) program was held on the campus of Hampton University from Monday, June 3, 1996, concluding Friday, July 28, 1996. This program targeted undergraduate physics students, who have completed at least their second year of course work in physics. The participants benefited from having the experience of both an educational and research environment.

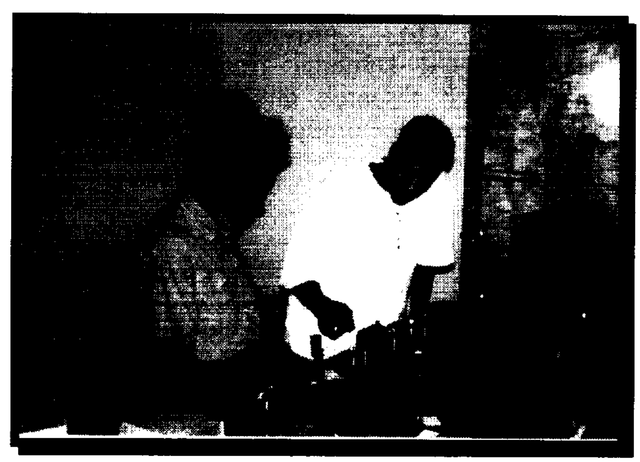

Figure 40. Graduate student Ms. Apriel Hodari checking an experiment by UnIPhy student Mr. Jason Jackson.

African American Male Math and Science Academy

Graduate students Ms. Valetta Davis, Ms. Apriel Hodari and Mr. Darrell Spraggins conducted introductory physics laboratory exercises with thirty middle school African American male students.

Figure 41. Graduate student Ms. Valetta Davis conducting physics exercises with AAMMSA participants.

National Conference of Black Physics Students 1995 and 1996

Hampton University graduate student, Ms. Apriel Hodari, was on the program committee for The National Conference of Black Physics Students' annual meeting. The 1995 meeting was held in Washington, D.C. The 1996 meeting was held on the campus of Fisk University in Nashville, Tennessee. Both conferences consisted of invited talks and poster sessions featuring prominent African American physicists and physics students. The conference was attended by well over three hundred African American physicists and physics students.

Figure 42. RCOP graduate student, Ms. Erica Jo Thompson was co-chair of the conference in 1995.

5.3 Teacher Enhancement

The Summer Institute for Teacher Enhancement (SIT) is a program funded by the U.S. Department of Energy (DOE). This program was hosted by the Thomas Jefferson National Accelerator Facility formally CEBAF. SITE provides hands-on research experiences for 50 participating middle and high school teachers. The teachers learned how to use lasers as a teaching tool in their sciences courses, toured the Graduate Physics Research Center and received laser pointers as an additional benefit.

Figure 43. Graduate student Mr. Eric Brass conducting a tour of his laboratory to the SITE participants.

Recruitment and Retention Workshop

The Department of Physics hosted the Washington Baltimore Hampton Roads - Alliance for Minority Participation (WBHR-AMP) Workshop on Successful Outreach Programs: recruitment and Retention. This workshop was held in McGrew Towers on the campus of Hampton University on November 17, 1995. This workshop focused on successful outreach programs for recruitment and retention of underrepresented science students. The objectives of this workshop were to explore opportunities in establishing linkages between four year universities and community colleges and to address key issues concerning the matriculation of students. The agenda is listed on the next page. Dr. Warren Buck, Professor of Physics moderated this workshop. We had informative talks by people with success on the theme of recruitment and retention. There were also working groups that focused on specific topics. The overall workshop was very successful.

SUCCESSFUL OUTREACH PROGRAMS: RECRUITMENT AND RETENTION

Department of Physics Workshop
Hampton University
17 November 95
McGrew Towers Assembly Rooms A & B

Agenda

Moderator: Dr. Warren W. Buck, *Professor of Physics - Continuous Electron Beam Accelerator Facility**

9:00 a.m. - 9:50 a.m.	**OPENING SESSION**	
9:00 a.m. - 9:20 a.m.	Registration/Continental Breakfast	
	Greetings	Dr. Calvin W. Lowe *Vice President for Research and Dean of Graduate College* Dr. Doyle A. Temple *Chair, Department of Physics Hampton University*
	Remarks	Dr. Robert D. Bonner *Dean of the School of Pure & Applied Sciences*
9:50 a.m. - 12:00 p.m.	**MORNING SESSION**	
	Retention at Jackson State University	Dr. Kunal Ghosh *Chair, Department of Physics and Atmosphere Science Jackson State University*
	Recruitment & Retention in SEMS	Dr. Mary Ellis *Chair, Department of Computer Science, Hampton University*
10:50 a.m. - 11:00 a.m.	*Coffee Break*	
	NASA Outreach Perspective	Dr. Samuel Massenberg *Director, Office of Education NASA Langley*
	Retention at Hampton University	Dr. Rodney Smith *Dean of Students Hampton University*
12:00 p.m. - 1:00 p.m.	**LUNCH**	
1:00 p.m. - 3:00 p.m.	**AFTERNOON SESSION**	
	Working Group A	Cause and effect of existing problems in undergraduate programs
	Working Group B	Effective recruitment and retention methods
	Working Group C	Linking four year and community colleges
	Working Group D	Tracking and communicating successful programs
	Working Group E	Attrition in the sciences
	Reports and Discussion of Directives	
3:00 p.m. - 5:00 p.m.	**CLOSING SESSION**	Dr. Warren W. Buck *Moderator*
	Implementation of Directives	
3:30 p.m. - 5:00 p.m.	Reception	

5.4 Seminar Series

The Department of Physics in conjunction with NuHEP, RCOP and CFRT held ajoint colloquium series each year. In this colloquium, distinguished scientists presented seminars on their research. just a few of the more than 120 presenters included: Noble Laureate and Harvard University Professor Dr. Nicolaas Bloembergen, Dr. M.S. Dresselhaus MIT Institute Professor of Physics and past President of the American Physical Society, and Dr. Gerard Mourou, Professor and Director, Center for Ultrafast Optical Science, University of Michigan.

Figure 44. Graduate student Mr. Christophe McCray with Nobel Laureate Dr. Nicolaas Bloembergen after his seminar on "The Daily Applications of Lasers".

Research Center for Optical Physics Optics Conference

The Research Center for Optical held its inaugural forum on September 22-23, 1993. More than 100 people from industry, universities and federal agencies attended. Mr. Paul Holloway, Director of NASA Langley Research Center gave the keynote address and Dr. William R. Harvey, President of Hmpton University gave the welcome address.

The Second RCOP Forum was held on September 23rd and 24th in McGrew Towers at Hampton University. Included were two days of technical sessions with invited talks, submitted talks and a student poster session.

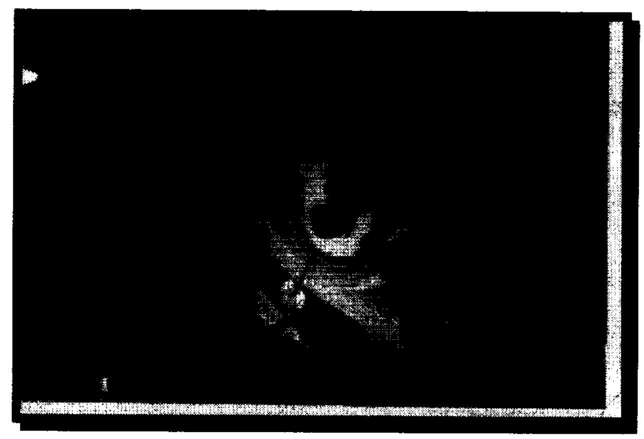

Figure 45. NASA Langley scientist presenting a lecture on LIDAR aplications at the second forum.

The forum began with opening remarks on the history of the physics department and RCOP by Dr. Demetrius Venable, Executive Vice President and Provost. This was followed by remarks from Dr. Frank Allario, Chairman of the Technical Advisory Committee and Dr. Doyle Temple Director of RCOP. Participants in the technical sessions included students and researchers from CCNY/CUNY, Fisk University, Georgia Institute of Technology, Hampton University, the University of Maryland, the University of Michigan, NASA LaRC, North Carolina A&T State University and Stephens Institute of Technology.The banquet was highlighted by a speech by Lynwood Randolph, the Manager of Information Standards at NASA Headquarters. There were also participants from government laboratories, industries and universities from around the country.

6. URC STUDENT INVOLVEMENT AND DEGREES AWARDED

6.1 Bachelors Degrees Awarded to Students That Have Worked in RCOP

Last Name Last, First MI	Gender/ Ethnicity	Major	Citenzenship	Year
Anderson, Andrea R.	Female African Am.	Electrical Engineering	US	1995
Atkins, Adontis	Male African Am.	Electrical Engineerring	US	1996
Bell, Raymond C.	Male African Am.	Airway Science	US	1996
Bonaparte, Justin	Male African Am.	Physics	US	1995
Coleman, Craig	Male African Am.	Physics	US	1993
Dumas-Hough, Keisha	Female African Am.	Physics	US	1995
Goss, Tyhesha N.	Female African Am.	Physics	US	1996
Hairston, Brian	Male African Am.	Physics	US	1995
Johnson, Alicia R.	Female African Am.	Physics	US	1993
Lane, Ryan	Male African Am.	Physics	US	1996
Lee, Krista	Female African Am.	Physics	US	1995
Lofton, Lakela	Female African Am.	Electrical Engineering	US	1995
Moore, Michael	Male African Am.	Computer Science	US	1994
Russell, Edgar	Male Aftican Am.	Physics	US	1994
Robinson, Travis	Male African Am.	Computer Science	US	1994

6.2 Bachelors Degrees to be Awarded in 1996-1997

Batth, Desireé	Female African Am.	Physics	US	1997
Clingman, Chekesha	Female African Am.	Physics	US	1997
Fields, Aisha	Female African Am.	Physics	US	1997
Hudson, Tosha	Female African Am.	Physics	US	1997
Hurts, Donald	Male African Am.	Electrical Engineering	US	1997
Lucas, Michael	Male African Am.	Physics	US	1997
Pendergrass, LeRuth	Female African Am.	Electrical Engineering	US	1997

6.3 Masters Degrees Awarded to Students That Have Worked in RCOP

Name Last, First MI	Gender/ Ethnicity	Citizenship	Major	Year
Allen-Wells, Donica	Female African Am.	US	Physics	1993
Cho, Yong Su	Male Korean	Korean	Physics	1992
Choi, Jaeho	Male Korean	Korean	Physics	1992
Copeland, Randolph	Male African Am.	US	Physics	1993
Han, Goowan	Male Korean	Korean	Physics	1993
Hodari, Apriel K.	Female African Am.	US	Physics	1994
Johnson, Alicia	Female African Am.	US	Physics	1995
Lee, Sangwoo	Male Korean	Korean	Physics	1994
Lee, Hyung R.	Male Korean	Korean	Physics	1994
McCray, Christophe	Male African Am.	US	Physics	1996
Nguyen, Dung X.	Male Vietnamese	US	Physics	1994
Terrell, Charles A.	Male African Am.	US	Physics	1994
Veal, Trina	Female African Am.	US	Physics	1993

6.4 Masters Degrees to be Awarded in 1996-1997

Name Last, First MI	Gender/ Ethnicity	Citizenship	Major	Year
Brass, Eric D.	Male African Am.	US	Physics	May 1997
Spraggins, Darrell	Male African Am.	US	Physics	May 1997
White, Renita A.	Female African Am.	US	Physics	May 1997
Williams, Mary	Female African Am.	US	Physics	August 1997

6.5 RCOP Doctoral Candidates

Name Last, First MI	Gender/ Ethnicity	Citizenship	Advisor	Expected Date
Brass, Eric	Male African Am.	US	Lyons	May 2000
Etop, Florence E.	Female African Am.	US	Lowe	May. 1997
Hodari, Apriel K.	Female African Am.	US	Temple	May. 1997
Lee, Hyung R.	Male Korean	Korean	Lyons	May 1998
Lee, Sangwoo	Male Korean	Korean	Chyba	May 1998
McCray, Christophe	Male African Am.	US	Chyba	May 2000
Nguyen, Dung X.	Male Vietnamese	US	Tabibi	May 1998
Sammuel, Kenneth R.	Male African Am.	US	Lyons	May 1999
Seo, Kang I.	Male Korean	Korean	Lowe	Aug. 1997
Smith, Cecily J.	Female African Am.	US	Lyons	May 1999
Spurlock, Melvin U.	Male African Am.	US	Lowe	May 1997
Terrell, Charles A.	Male African Am.	US	Tabibi	Dec 1997

6.6 Ph.D. Candidates: Biographical Sketches

Ms. Florence E. Etop **Advisor: Calvin Lowe**

I graduated from Alabama A&M University in 1993 with a Master degree in Applied Physics. I am in the Ph.D. program at Hampton University studying gain enhancement of multilayer organic thin films. After graduation, I plan to pursue a postdoctoral position either in industry or educational system and eventually become a faculty member at an HBCU.

Ms. Apriel Hodari **Advisor: Doyle Temple**

I received my Bachelor of Science in Electrical Engineering from Purdue University in 1989, and my Master of Science in Physics from Hampton University in 1993. I am a doctoral candidate in optical physics at Hampton University studying optical (particularly photorefractive) properties of rhodium-doped barium titanate. Upon completion of my doctoral degree, I plan to conduct research and teaching activities in an academic setting.

I am a member of The American Physical Society, the Society of Physics Students, the Society of Black Physicists, the Institute of Electrical and Electronics Engineers, the Optical Society of America and the Virginia Academy of Science. I was National President (1993-96) of Phi Sigma Rho National Sorority, Item Writer (1995-96) for the ACT Assessment Mathematics Test and recepiant of the Outstanding Physics Teaching Assistant (1995) Award from the American Association of Physics Teachers.

Mr. Hyung Rip LeeAdvisor: **Advisor: Donald Lyons**

I graduated from Kyungbook National University in 1991 with a Bachelor of Physics. I am in the Ph.D. Program at Hampton University studying Fiber Optics for Bragg grating sensor applications. After graduation, I plan to pursue a doctoral position in University or research Lab. for more experiments.

Mr. Sangwoo Lee **Advisor: Thomas Chyba**

I graduated from Soongsil University in 1986 with a Bachelor of Science in Physics and received my Master of Science in Physics from Hampton University in 1994. I am a doctoral candidate at Hampton University. I am studying a laser remote sensing, especially methane measurements in the atmosphere using the DIAL(Differential Absorption Lidar) method. I plan to pursue a postdoctoral position in a school or industry. I am a member of The American Physical Society and the Korean Engineer and Science in America.

Christophe L. McCray **Advisor: Thomas Chyba**

I graduated from North Carolina A&T State University with a BS degree in physics and entered Hampton University in 1993. I am a doctoral candidate in physics. My research is concerned with the nonlinear frequency conversion of laser radiation via stimulated Raman scattering in barium nitrate crystals. Our research goal is to utilize this process to generate uv wavelengths suitable for ozone lidar measurements. I am a recipient of an Office of Naval Research Fellowship, a National Physical Sciences Consortium Fellowship, and a Virginia Space Grant Fellowship.

Mr. Dung Xuan Nguyen **Advisor: Bagher M. Tabibi**

I received a Bachelor of Science in Electrical Engineering from Old Dominion University in 1990 and a Master of Science in Physics (specially in Plasma Physics) from Hampton University in 1994. I am a Ph. D. candidate in Physics at Hampton University studying Advanced Propulsion System. I plan to pursue a postdoctoral position either in industry or academic setting which will provide opportunities to conduct research in Propulsion System or related field.

I have been a member of the Institute of Electrical and Electronics Engineers, the American Physical Society, and the Society of Physics Students. I am also a volunteer for Vietnamese Community in Hampton Road region, American Red Cross, and Hampton Baptist Church.

Mr. Kenneth R. Samuel **Advisor: Donald Lyons**

My current research area concerns optical sensors, intra-fiber devices, device fabrication techniques, and novel fiber optic applications. I am a member of the Optical Society of America and the American Physical Society, Society of Physics

Mr. Kang I. Seo **Advisor: Calvin Lowe**

I graduate from Alabama A&M University in 1994 with a Master degree of Physics Department. I am in the Ph.D. program at Hampton University studying optical properties for organic thin film devices. I plan to pursue a postdoctoral position in a school/industry.

Ms. Cecily J. Smith **Advisor: Bagher Tabibi**

I graduated in 1987 from Norfolk State University with a Bachelor of Science Degree in Physics. I also earned a Master of Science Degree from Hampton University's Department of Physics with a thesis entitled "A Computer Model of the Diffuse Reflectance of $LiInSe_2$." As a doctoral candidate in the Department of Physics at Hampton University, I am currently performing research on fiber optic Bragg gratings. As an Assistant Professor, I have instructed introductory physics and mathematics courses at some of the nation's HBCUs. I am currently a math and physics tutor for ONR's in Physics is one step that she is pursuing toward making a continued contribution to the education of our nation' youth.

Mr. Melvin Spurlock **Advisor: Calvin Lowe**

I graduated from Virginia State University in 1990 with a Bachelor of Science degree in Physics and in 1992 with a Master of Science in Physics. I am in the Ph.D. program at Hampton University studying Hyperthermal Ion Scattering from Organic Thin Films. After graduation, I plan to start a research company that will put the safety and health of the environment first in developing new technologies and eventually become a faculty member at an HBCU.

Mr. Charles A. Terrell **Advisor: Bagher Tabibi**

I graduated from Norfolk State University in 1988 with a Bachelor of Science degree in Physics and obtained my Master of Science degree in Physics at Hampton University in 1993. I am currently a Ph.D. candidate in Physics at Hampton University participating in research that applies a non-intrusive, electron beam diagnostic technique to gaseous flowfields. After my graduate studies, I plan to pursue a career as a research scientist in industry or government.

7. URC LEVERAGED FUNDING

7.1 Research and RCOP Support Funding

PI	AGENCY	TITLE	AMOUNT	PERIOD
K. Han	ONR	Intense Excitation Source	81,267	1/92 - 12/92
K. Han	NASA	Investigation of Polymer Liquid Crystals	109,733	10/92 - 9/93
D. Venable	NASA	Spaceborne Photonics Institute	673,000	5/92 - 5/93
B. Tabibi	AFOSR	Advanced Thermal and Electric Propulsion	431,650	9/94 - 8/95
B. Tabibi	AFOSR	Radiative Processes in Nitrogen Ions	25,000	8/93 - 7/94
U. Farrukh	ARL	Far Field Diffraction Patterns in Composite	30,000	10/93 - 12/93
G. Simms	NSF	Fiber Optic Sensors and Smart Materials	312,069	1/94 - 12/97
B. Tabibi	AFOSR	Thermal-Electric Prouplsion with Magneto-plasma	632,204	1/94 - 12/97
D. Lyons	NASA	Fiber-Optic Sensors	275,000	6/95 - 5/98
T. Chyba	NASA	Laser Research for Tropospheric Water Vapor Measurements	84,000	8/95 - 7/97
U. Hommerich	Army	Optical characterization of rare earth doped wide band-gap semiconductors	170,000	7/96 - 6/99
T. Zenker	NASA	Interpretation of Lidar and Satellite Data Sets Using a Global Photochemical Model	143,000	7/95 - 6/97
Grant Total			**2,966,923**	

Equipment Donation

D. Lyons	Grumman	Fiber Optics Laboratory	$ 350,000	1994
D. Venable	AT&T	Electron Microscope	$ 125,000	1994
D. Temple	Deltronic Inc.	Photorefractive Crystals	$ 35,000	1995
B. Tabibi	NASA LaRC	Lasers and Spectroscopic Equipment	$ 87,000	1996
Donation Total			**$ 597,000**	

UNIVERSITY CONTRIBUTION

		Item	**Amount**	
		GPRC Renovation	$ 230,000	
		Overhead Matching (20.3%)	$ 820,000	
University Total			**$ 1,050,000**	

7.2 Student Scholarships and Fellowships

		Graduate Students			
NAME	**GENDER**	**ETHNICITY**	**AMOUNT**	**AGENCY**	**PERIOD**
Eric Brass	Male	African American	$ 5,000	Va. Space Grant	9/96 - 8/97
Romuald David	Male	African	$ 45,000	NASA	9/95 - 8/ 98
Apriel Hodari	Female	African American	$ 10,000	Va. Space Grant	9/94 - 8/96
Alicia Johnson	Female	African American	$ 45,000	ONR	8/93 - 5/95
Christophe McCray	Male	African American	$ 95,000	ONR	6/93 - 8/97
Kenneth Samuel	Male	African American	$ 10,000	Va. Space Grant	9/95 - 8/97
Cecily Smith	Female	African American	$ 28,000	ONR	9/93 - 10/95
Charles Terrell	Male	African American	$ 10,000	Va. Space Grant	1992/93 & 1995/96
Trina Veals	Female	African American	$ 10,000	Va. Space Grant	9/93 - 8/95
Aquaire Walton	Male	African American	$ 10,000 $ 25,000	Va. Space Grant ONR	9/92 - 8/94 8/93 - 12/94
TOTAL					

		Undergraduate Students			
NAME	**GENDER**	**ETHNICITY**	**AMOUNT**	**AGENCY**	**PERIOD**
Desiree Batth	Female	African American	$ 75,000	ONR - SEMS	9/93 - 5/97
Amaris Carr	Female	African American	$ 75,000	ONR - SEMS	9/95 - 5/99
Chekesha Clingman	Female	African American	$ 75,000	ONR - SEMS	9/93 - 5/97
Craig Coleman	Male	African American	$ 35,000	ONR - SEMS	9/92 - 5/94
Tyeshia Goss	Female	African American	$ 75,000	ONR - SEMS	9/92 - 5/96
Ryan Lane	Male	African American	$ 75,000	ONR - SEMS	9/92 - 5/96

8. Faculty Biographical Sketches

8.1 Current RCOP Research Faculty Members

Dr. Yoon Choi, Postdoctoral Fellow 1995 - 1996

Dr. Choi received his Ph.D. from Pohang University of Science and Technology in 1994. His field of specialization is Spectroscopic Diagnostics and Plasma Dynamics. His research is concentrated on measuring physical parameters of a solar thermal electrical propulsion system.

Dr. Thomas Chyba, Assistant Professor of Physics 1995 - 1996

Dr. Chyba received his Ph.D. from the University of Rochester in optical physics. From 1990 until 1993 , he was a National Research Council Research Associate with Dr. Edward Browell's Lidar Applications Group in the Chemistry and Dynamics Branch, Atmospheric Sciences Division, of the NASA Langley Research Center. From 1993 until 1995, he was a Research Scientist at the College of William and Mary associated with that same group. He joined the Hampton University in 1995 and is now an Assistant Professor of Physics and a member of the university's newly formed Center for Atmospheric Sciences. His laboratory in the Research Center for Optical Physics at Hampton University specializes in laser development for lidar applications. He has authored/co-authored over 25 technical articles and has presented numerous papers at conferences and technical meetings. Dr. Chyba is a member of the Optical Society of America, the American Physical Society, and the International Society for Optical Engineering

Dr. Chuan He, Postdoctoral Fellow 1996

I graduated from the University of South Florida in August, 1994, with a Ph.D. in Engineering Science. My graduate research concentrated in lasers and electro-optics with application to laser remote sensing and lidar. While in Dr. Chyba's group at Hampton, I designed and tested a Raman oscillator to generate visible wavelengths suitable for frequency doubling to the ultraviolet for ozone lidar measurements. In 1996, I accepted a position with Exclusive Design Company in Fremont, Ca.

Dr. Uwe Hömmerich, Assistant Professor of Physics 1995 - 1996

Dr. Uwe Hömmerich received his Ph. D. in physics from the University of Hamburg in 1994. His dissertation research was on the optical spectroscopy of new transition metal laser materials. He spent a postdoctoral year at the University of Wisconsin-Madison before he joined the Department of Physics at Hampton University in 1995. Dr. Hömmerich has authored/co-authored over 35 technical articles in the area of optical spectroscopy of rare earth and transition metal based solid-state laser materials.

Dr. Calvin Lowe, Professor of Physics and Vice President for Research 1995 - 1996

Dr. Lowe received his B.S. physics degree from NC A&T University, Greensboro and his S.M. and Sc.D. degrees in plasma physics and Solid state Physics respectively from MIT, Cambridge, MA. He has worked as Assistant professor in the department of physics & astronomy, University of Kentucky, ASEE Summer Faculty Research Program, NASA LaRC, Hampton, VA. Associate Professor & Chair Physics Department, Hampton University, VA., Professor of Physics & Chair Department of Physics, Alabama A&M University, AL. At present he is Vice President for Research at Hampton University, Hampton, VA., a position he joined in August 1995. His area of research include Photonic Bandgap Crystals (PBC) for developing a light source which has all the important properties of laser and is single mode, and thrasholdless. His other interests are Quantum well lasers (QWL), Vertical Cavity Surface Emitting Lasers (VCSEL), Photonic Bandedge Lasers (PBL), and Optoelectronic devices. He concentrates on Organic thin films for his research. Dr., Lowe has several research papers to his credit including invited talks at Indian National and International conferences.

Donald Lyons, Associate Professor of Physics 1993 - 1996

Dr. Lyons received his B.S. degree in physics from Grambling State University and his M.S. and Ph.D. degrees in physics from Stanford University. He has held a number of technical positions: Senior Scientist, Corning Glass Works, Applied Physics Department, Corning, New York. Lawrence Livermore National Laboratory: Z-Division: Applied Technology, and Senior Research Scientist, Grumman Aerospace Corporation: Senior Sciences and Materials and Structures Groups in Grumman corporate Research Center. He joined the Hampton University faculty in August, 1993 as a senior scientist and Grumman Aerospace research associate professor of physics. His area of research include the application of intrinsic and extrinsic fiber optic Fabry-Perot sensors (as well as distributed Bragg reflection fiber sensors) to Smart materials and structures. Dr. Lyons has more than 25 patents and technical publications in this area of research.

Dr. Satish Mathur, Research Associate Professor of Physics 1995 - 1996

Dr. Satish Mathur received his B.Sc. and M.Sc. degrees from Rajputana University, India, and Ph.D. degree from Agra University, Agra, India. He did his post doctoral work at Georgia C. Marshal Space Flight Center, Huntsville, Al as a NAS-NRC post doctorate Resident Research Associate. After three years post-doctoral work he joined Indian Institute of Technology (IIT), New Delhi as an assistant Professor of Physics (equivalent of associate professor in US universities). In 1980 he was promoted to the rank of Professor at the same institute. He joined Hampton University in 1995 as a Research Professor. His research interests are in Photonic Bandgap Crystals (PBC) for developing a light source which has all the important properties of laser and is single mode, and thresholdless. His other interests are Quantum well lasers (QWL), Vertical Cavity Surface Emitting Lasers (VCSEL), Photonic Bandedge Lasers (PBL), and Optoelectronic devices. Dr. Mathur has 78 refereed publications, 24 papers in conference proceedings, and 4 review articles in books and journals. He has delivered 10 invited talks at National and International conferences. In 1996 he was honored by a National award for outstanding work on Ferroelectrics and dielectrics by India. He is a member of American Physical Society, Indian Physics Association, Semiconductor Society (India) - He was Chairman of the society from 1992-94, Indian Association of Physics Teachers, and Instruments Society of India. Dr. Mathur was a visiting Scientists at University of Strathclyde, Glassgow, U.K. for one year (1971), and Professor and Head of Physics department, University of Maiduguri, Nigeria for two years (1981-83).

Ms. Carlane Pittman, Director for Outreach 1995 - 1996

Ms. Pittman received her BS degree in physics from Spelman College and her MA degree in education from Hampton University. Before becoming the Director for Outreach she was the Associate Director for Outreach for the Nuclear/High Energy Physics Research Center for Excellence. Ms. Pittman was responsible for implementation of the outreach component for this center. She has successfully maintained an international outreach program which lead her into the Director position. This new position entails enhancement of the outreach program, recruitment of students into physics programs and advisement of undergraduate and graduate students on their curricula. Ms. Pittman also serves as co-advisor for the Society of Physics Students.

Bagher Tabibi, Associate Professor of Physics 1992 - 1996

Dr. Tabibi received his Ph.D. from Moscow State University. His area of research involves the development of laser diagnostic experiments for investigating hypersonic flow field characteristic. The techniques used include laser induced fluorescence, Raman scattering and laser absorption. These non-intrusive optical spectroscopic techniques offer the possibility of detecting molecules and atoms, measuring species concentrations, determining energy level population distribution and probing energy transfer processes (including relaxation) in molecules and atoms. He joined the Hampton University faculty in 1983 and is currently an Associate Professor of Physics.

Dr. Doyle Temple, Associate Professor of Physics and Chair 1994 - 1996

Dr. Temple received his B.S. Degree from Southern University and his Ph.D. from the Massachusetts Institute of Technology. He was an Assistant Professor of Physics at Louisiana State University from 1988 to 1994 before joining Hampton University as Associate Professor of Physics and Chair in 1994. His research interests are in crystal growth and spectroscopy of new optical materials. Dr. Temple has 12 refereed publications and 17 conferences presentations. He is a member of the American Association of University Professors, the American Association of Physics Teachers, the Institute of Electrical and Electronics Engineers, the International Society for Optical Engineering, the Optical Society of America and the Sigma Pi Sigma Physics Honor Society.

Dr. Qingnan Wang, Post Doctoral Fellow 1995 - 1996

Dr. Wang received his Ph.D. in Physics from Purdue University in 1994. He is currently a postdoctoral fellow of physics in the Research Center for Optical Physics at Hampton University. His expertise is in the areas of charge transport processes, band-edge electrooptic effects, and nonlinear optics in solid state materials. His current research focuses on ferroelectric crystals and semiconductor-metal phase transition.

Dr. Thomas Zenker, Research Assistant Professor 1995 - 1996

Dr. Zenker received his Diploma (M.S.) and Ph.D. from J.-G.-University in Mainz, Germany, in 1986 and 1990, respectively. From 1986 until 1995 he was a Ph.D. student and post-doctoral scientist at the Max-Planck-Institute for Chemistry in Mainz, Germany, before coming to Hampton University in 1995. Dr. Zenker is a Visiting Research Assistant Professor in the Research Center for Optical Research. He is working on global photochemical modeling in close collaboration with Dr. Fishman at the NASA Langley Reseach Center. At Hampton University Dr. Zenker is collaborating with Dr. Chyba on an OPO-based infrared laser system for lidar remote sensing of atmospheric trace gases. He has been an author or co-author on about 20 refereed journal articles and book chapters and presented several papers at international meetings. He participated in several international field campaigns investigating the composition and chemistry of the troposphere, including the analysis and interpretation of the measurements using photochemical simulations.

8.2 Former Faculty Members of RCOP

Usamah Farrukh, Professor of Electrical Engineering (1992 - 1994)
Dr. Farrukh received his Ph.D. in Electrical Engineering from the University of Southern California. His areas of research include laser system modeling; optical systems and detectors; laser propagation in scattering media; atmospheric optical properties and analysis and software development for optical and ballistic systems. He has more than 30 publications in refereed journals.

Dr. Kwang Han, Professor of Physics (1992 - 1993)
Dr. Han's research interests are in plasma and laser physics. He has more than 27 years of service at Hampton University. He received his Ph.D. degree in physics from the College of William and Mary.

In Hwang, Associate Professor of Physics (1992 - 1994)
Dr. Hwang received his Ph.D. degree in physics from the Korean Advanced Institute of Science. His area of research includes the use of diode lasers in the development of a solid state lasers.

Dr. Nelson Jalufka, Associate Professor of Physics (1992 - 1994)
Dr. Jalufka received his Ph.D. degree in physics from the University of Colorado at Boulder. He joined the physics department at Hampton University in 1990. Prior to that he was a senior research scientist at NASA LARC. His area of research is atomic and molecular spectroscopy.

Arlene Maclin, Research Professor of Physics (1992 - 1994)
Dr. Maclin received her B.S. degree in physics from north Carolina A&T State University, M.S. degree from the University of Virginia and her Ph.D. degree in theoretical solid state physics from Howard University. Dr. Maclin has held a number of technical positions and has received a number of honors since graduate school. Her area of research interest include bandstructure calculations of magneto-optical materials, science education and science and technology policy studies.

Garfield Simms, Assistant Professor of Applied Mathematics (1992 - 1993)
Dr. Simms received his B.S. Degree in physics from Delaware State University and his M.S. and Ph.D. degrees in electrical engineering from the University of Delaware. His area of research interest include fiber optic communications devices.. Dr. Simms has two patents in the area of fiber optic transmission lines.

Carl Spight, Adjunct Professor (1992 - 1993)
Dr. Spight, Director of Scientific Research, Jackson and Tull and Graham has had extensive university and high technology experience, both as a manager and as a scientist-technologist. In the university he has held the position of professor of physics (tenured), and chairperson of a department, dean of a school (Arts & Sciences), executive assistant to a university president, and director of an office of information technology. In industry he has directed a division with more than 30 software development efforts under government (DOD, FAA) contracts.

Alphonso Smith, AssociateProfessor of Electrical Engineering (1992 - 1994)
Dr. Smith is a faculty associate of RCOP and. His research interest are in ultrasonics and the use of fiber optics to study smart materials. He joined the Hampton Unversity community in 1991. He received his Ph.D. degree in electrical engineering from Virginia Polytechnic and State University.

Demetrius Venable, Vice President for Research (1992 - 1995)
Dr. Venable is the director and principal investigator of RCOP. He has held prior positions at the university serving as professor and chariman of physics, Dean of the graduate school and currently Vice President for Research. He has more than 14 years of service to Hampton University and holds a Ph.D. degree in physics from American University and is an African American.